Canada

NATIONAL SYMPOSIUM ON LIGHTING DESIGN FOR HOSPITALS
MARCH 15 & 16, 1983

Health Facilities Design Division
Health Services & Promotion

Health and Welfare Canada

The Canadian Hospital
Engineering Society

WELCOME

T.M. Ogrodnik M. Arch.
Director Health Facilities Design
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Welcome on behalf of National Health and Welfare Canada, Health Facilities Design Division (HFD) and the Canadian Hospital Engineering Society (CHES) who, as you know, have cooperated with my division (HFD) in developing and organizing this symposium.

Mr. Callan - wearing his second hat - the hat of the president of the CHES may wish to tell you a little bit about the CHES therefore I shall confine my remarks to HFD's sphere of activities (and hopefully influence)

HFD basically, has two programs which it currently pursues:

- the development of health facilities planning and design guidelines and,
- investigation of the design impact on health - well-being of the user of the built environment.

The first program includes research into innovative planning and design, design techniques, construction materials and efficient hospital plant operation; it includes studies of energy conservation in design and hospital operating procedures; it also includes the establishment of national data base for health facility planning and design.

The second program concerns the study of the relationship between the individual (male and female) and individual's physical (built) environment. This program stems from our long standing commitment to the promotion of health through "properly" designed physical environment.

Our mandate in the federal-provincial-private sector scheme of things may be expressed by changing president Theodore Roosevelt's motto of: "speak softly and carry a big stick" to: "speak convincingly and give the sticks to the persons who are in a position to use them"

This symposium on lighting design for hospitals, as you must have gathered by now looking at the program, relates to both HFD's basic activities.

It has to do with design technology of lighting and the well-being of human visual and linked non-visual systems.

Its purpose is to examine some of the critical elements, in the design of lighting systems, in hospitals and to explore and evaluate basic principles and some new concepts for resolving problem areas.

The theme of the symposium is: "PATIENT ORIENTED HOSPITAL LIGHTING: DESIGN PRIORITIES AND CONFLICTS"

The program will focus on visual performance, impact of colour on lighting, existing and new artificial light sources and their effectiveness, psychological aspects of the visual environment, energy efficiency of the lighting system, lighting problem areas, lighting standards and codes for hospitals, maintenance and life cycle cost analysis of lighting systems.

You may be interested to know that this symposium was preceeded by another conference in 1981. It is unfortunate that the proceedings of the "Light, Health and Design Conference" could not have been in your hands prior to this symposium since, I believe, you would have gained another perspective with which to view the issues you will be tackling here.

However, in the next two days, I hope, that you will acquire some extra knowledge, and I also hope that you will share freely the knowledge you possess with those of us who are less generously endowed in this commodity (knowledge that is).

Welcome again and successful symposium!

INTRODUCTION

Harry Callan P. Eng.
Consulting Electrical Engineer
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Lighting, both natural and artificial, plays an important role in the life of the hospitalized patient. This role is multifaceted and is related to the numerous interactions the patient experiences with his luminous environment in terms of his health, safety, comfort, mental well being, morale, the quality of medical treatment he receives and the speed with which he recovers.

It is because of these factors that health care facility planners and designers have an important responsibility to discharge. That responsibility is to ensure that the hospitals lighting system is planned, designed, constructed and controlled so that it will perform at maximum functional efficiency and effectiveness. Most important, the total performance of the lighting system must be such that the net result will be improved service to the patient in all areas of diagnostic evaluation, medical treatment and professional care.

The purpose of this symposium is to examine some of the critical elements in the design of lighting systems in hospitals and to explore and evaluate basic principles and some new concepts for resolving problem areas.

The speakers who will present papers and take part in the discussions are professionals with a wide background of specialized knowledge and experience. They represent researchers, teachers, planning consultants, designers, manufacturers and users of lighting systems. The program includes ample opportunities for all of us to examine and evaluate existing lighting concepts and by discussion, to vigorously appraise the way in which present "design-and-use" problems are tackled and resolved.

I wish to express my sincere appreciation and thanks to the speakers, for the effort they have put forth in the preparation of their presentations. From what I have seen of their work I believe we are in for a very stimulating and interesting two days.

As President of the C.H.E.S., I would like to extend to everyone a most sincere welcome and best wishes for a most rewarding and informative conference.

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There are a few basic principles relating to the physical nature of "light" and its interaction with various detectors that should be understood by lighting designers.

From a physics point of view light is radiant energy, and it comprises just those wavelengths or frequencies which evoke a visual response. This is a very small part of the very extensive electromagnetic spectrum as shown in Figure 1. It is probably less confusing to refer to this energy as optical radiation and to describe it in terms of radiometric units and concepts. In lighting we are primarily concerned (although not exclusively) with how the human eye reacts to this optical radiation. Figure 1 indicates the colour sensation or qualitative response experienced, but gives no idea of the quantitative response. Figure 2, the relative luminous efficiency or V curve, shows the relative quantitive response of the light adapted eye to optical radiation of different wavelengths. To evaluate the quantitative effect of optical radiation as "light" the two must be combined as shown in Figure 3 and the bottom integral ($_{e3}$) must be multiplied by a constant Km (683 lumens/watt) to obtain the luminous flux in lumens from the source.

It is also of interest, particularly in hospital design, to consider some other uses of radiant energy produced by "light" sources. Strictly speaking, the useful energy is produced at slightly shorter (ultraviolet) or longer (infrared) wavelenghts than those represented by the visible spectrum, but they are normally included in the illumination field. Ultraviolet lamps are often used for their bactericidal or erythemal effects and appropriate response curves for these effects, (not the V curve) must be combined with the source radiation to evaluate the overall effect. Radiometric or special units should be used for ultraviolet and infrared effects not photometric units.

Table 1 shows a summary of the major radiometric and photometric quantities which are usually encountered. In every case the photometric quantity is the radiometric quantity weighted by the V curve for the human eye as shown in Figure 3

There are two photometric quantities that are often confused by lighting designers: illuminance and luminance (brightness). Figure 4 defines illuminance as the luminous flux density incident on a surface, hence the unit: lumen per sq. metre. Figure 5 illustrates the concept of the solid angle and Figure 6 defines the term luminous intensity as a directional bundle of luminous flux. Figure 7 combines these two quantities to express the illuminance in the well known inverse square law form combined with the cosine law.

Figure 8 illustrates the concept of luminance. As the eye in the figure indicates, this quantity represents what the eye sees when it views a source or an illuminated surface. The observer never sees illuminance directly, just the result of that incident light interacting with an object.

The spectral distribution of energy, that a source emits interacting with an object that itself has specific spectral reflecting and/or transmitting characteristics, controls the brightness of an object and its colour. It is the brightness distribution in a space that controls the quality of the lighting, not the illuminance alone. Thus a design based exclusively on illuminance specifications may give a totally unsatisfactory luminous environment if surface and object characteristics are not given due consideration.

TABLE 1

RADIOMETRIC AND PHOTOMETRIC UNITS

RADIOMETRIC			PHOTOMETRIC		
TERM	SYMBOL	UNIT	TERM	SYMBOL	UNIT
Quantity of radiant energy	Q_e	joule, erg, watt-sec	Quantity of luminous energy	Q	lumen-sec
Radiant flux (power)	$F_e(P_e)(\phi_e)$	watt	Luminous flux	$F\ (\phi)$	lumen
Radiant intensity	$I_e = \frac{DF_e}{d\omega}$	watt/steradian	Luminous intensity	$I = \frac{dF}{d\omega}$	lumen/steradian
Irradiance	$E_e = \frac{dF_e}{dA}$	watt/unit area	Illuminance	$E = \frac{dF}{dA}$	lumen/unit area
Radiant Exitance	$M_e = \frac{dF_e}{dA}$	watt/unit area	Luminous Exitance	$M = \frac{dF}{dA}$	lumen/unit area
Radiance	$L_e = \frac{dI_e}{dA\ \cos\theta}$	watt/unit area and per steradian	Luminance	$L = \frac{dI}{dA\ \cos\theta}$	candela/unit area

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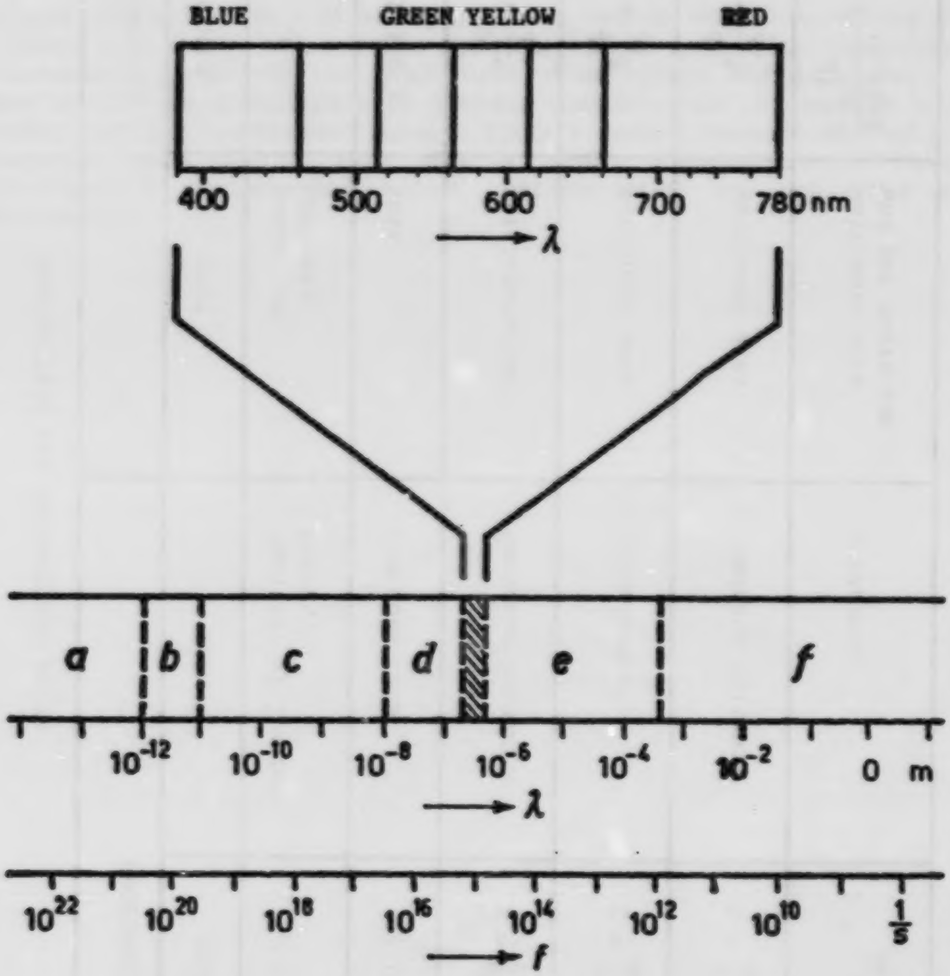
Fig.1


BLUE
GREEN YELLOW
RED
400
500
600
700
780 nm
→ λ
a
b
c
d
e
f
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
0 m
→ λ
10^{22}
10^{20}
10^{18}
10^{16}
10^{14}
10^{12}
10^{10}
$\frac{1}{s}$
→ f

a - cosmic rays
b - gamma rays
c - X rays
d - UV rays
e - infrared
f - communications and power transmission

Longueur d'ondes et fréquences des oscillations électromagnétiques
Wavelengths and frequencies of electromagnetic oscillations
Wellenlängen und Frequenzen der electromagnetischen Schwingungen

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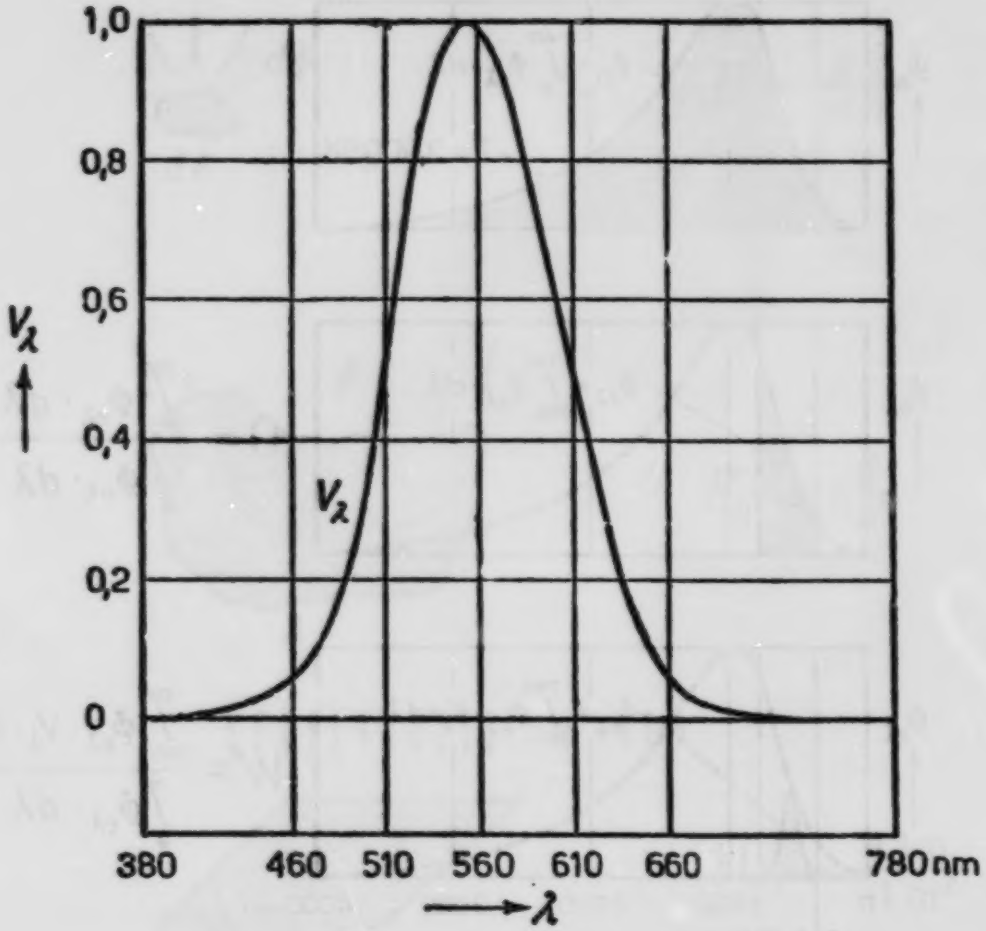
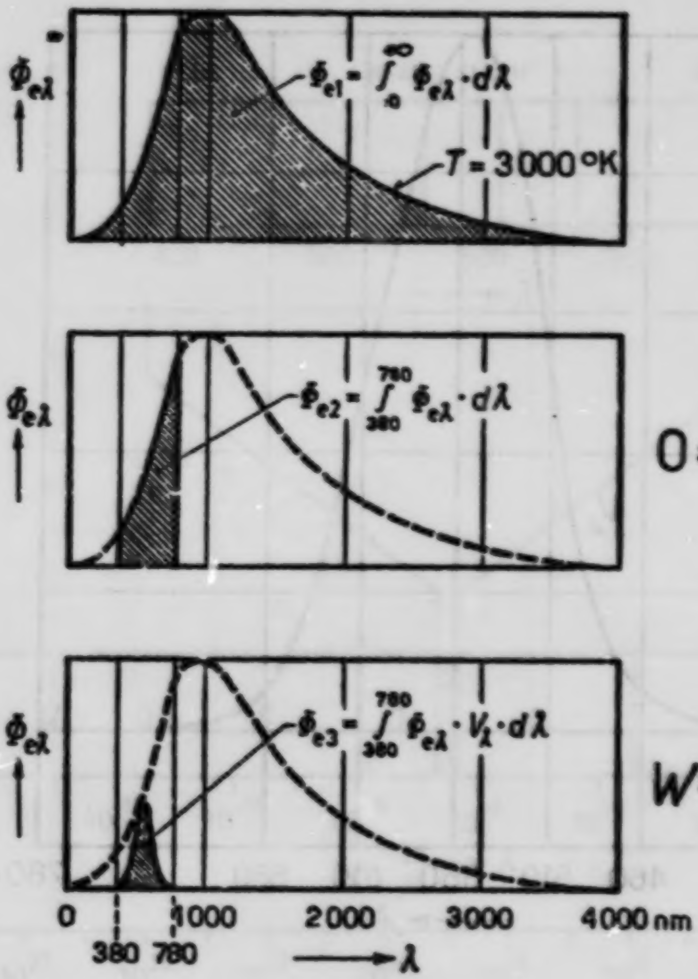
Fig.2



$$1\,\text{nm} = \frac{1}{10^9}\,\text{m}$$

Efficacité lumineuse relative pour la vision photopique V_λ
Relative luminous efficiency for photopic vision V_λ
Spektraler Hellempfindlichkeitsgrad für Tagessehen V_λ

Fig. 3

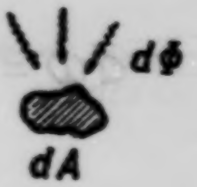


$$O = \frac{\int_{380}^{780} \Phi_{e\lambda} \cdot d\lambda}{\int_0^\infty \Phi_{e\lambda} \cdot d\lambda}$$

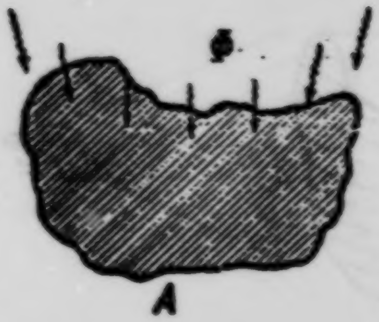
$$W = \frac{\int_{380}^{780} \Phi_{e\lambda} \cdot V_\lambda \cdot d\lambda}{\int_0^\infty \Phi_{e\lambda} \cdot d\lambda}$$

Efficacité optique et visuelle du rayonnement d' une lampe à incandescence
Optical and visual efficiency of the radiation of an incandescent lamp
Optischer und visueller Nutzeffekt der Glühlampenstrahlung

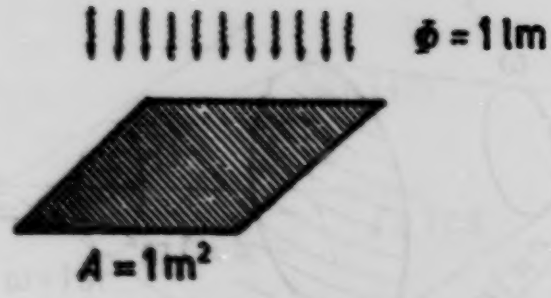
Fig.4



$$E = \frac{d\Phi}{dA}$$



$$E_m = \frac{\Phi}{A}$$



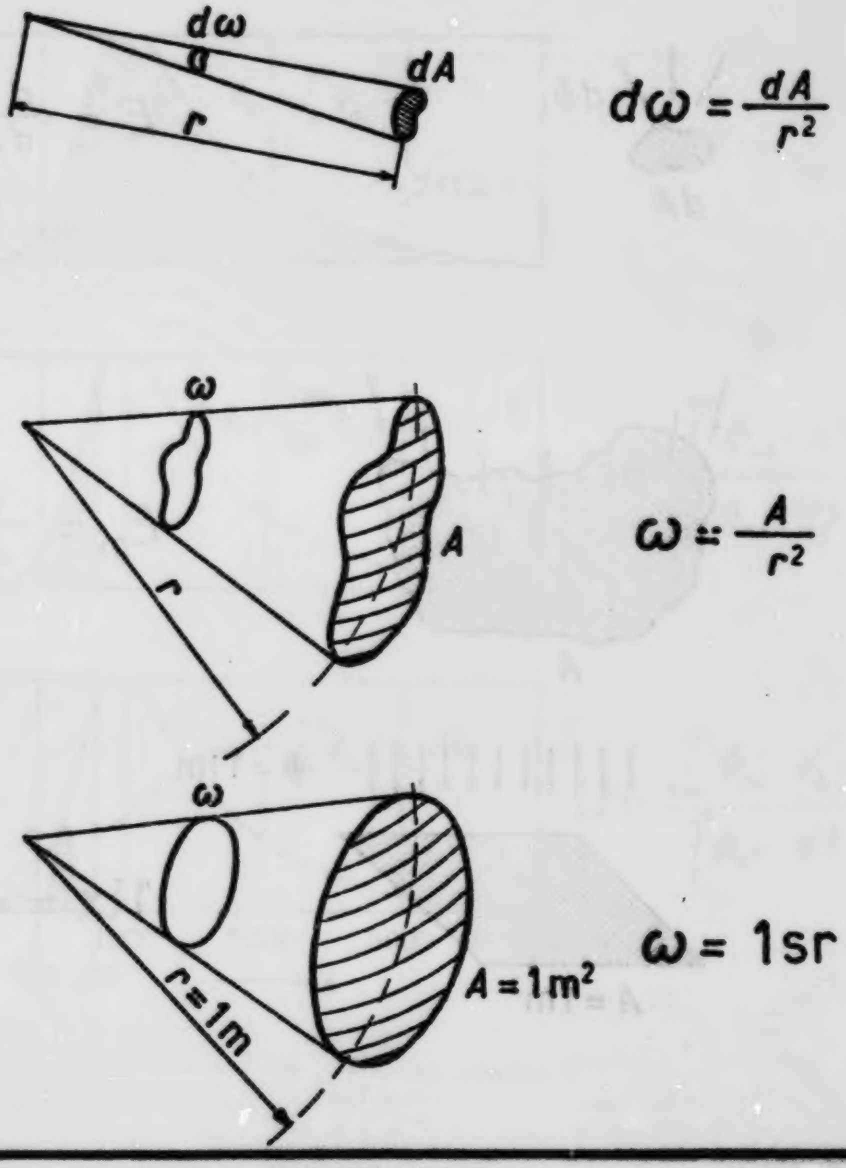
$$1\,\mathrm{lx} = \frac{1\,\mathrm{lm}}{1\,\mathrm{m}^2}$$

Eclairement E

Illuminance E

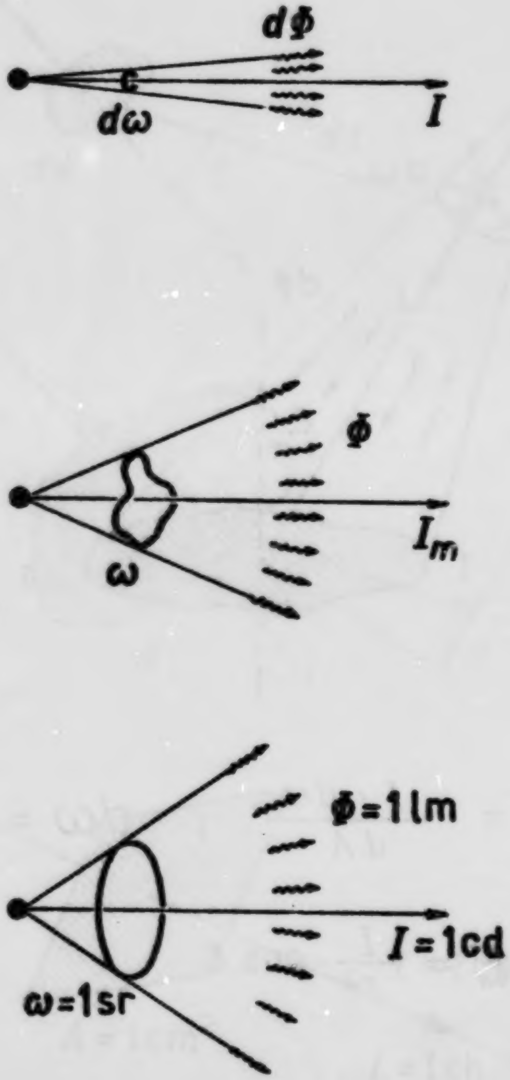
Beleuchtungsstärke E

Fig.5


dω
dA
r
$d\omega = \frac{dA}{r^2}$
ω
A
r
$\omega = \frac{A}{r^2}$
ω
r=1m
A=1m²
ω = 1sr

Angle solide ω
Solid angle ω
Raumwinkel ω

Fig.6



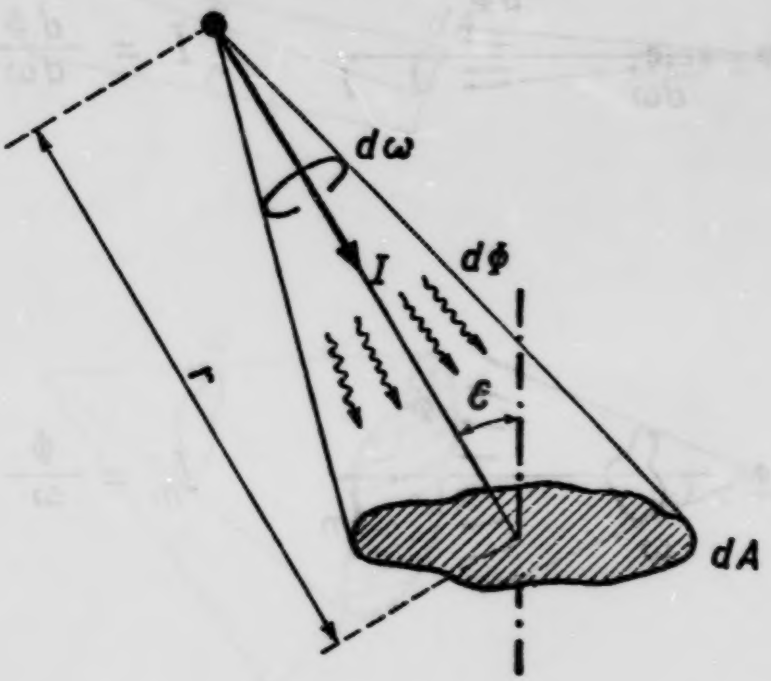
$$I = \frac{d\Phi}{d\omega}$$

$$I_m = \frac{\Phi}{\omega}$$

$$1\,\mathrm{cd} = \frac{1\,\mathrm{lm}}{1\,\mathrm{sr}}$$

Intensité lumineuse I
Luminous intensity I
Lichtstärke I

Fig. 7



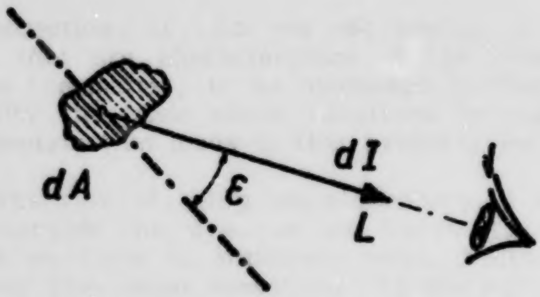
$$E = \frac{d\Phi}{dA} = \frac{I \cdot d\omega}{dA} \quad ; \quad d\omega = \frac{dA}{r^2} \cdot \cos\varepsilon$$

$$E = \frac{I}{r^2} \cdot \cos\varepsilon$$

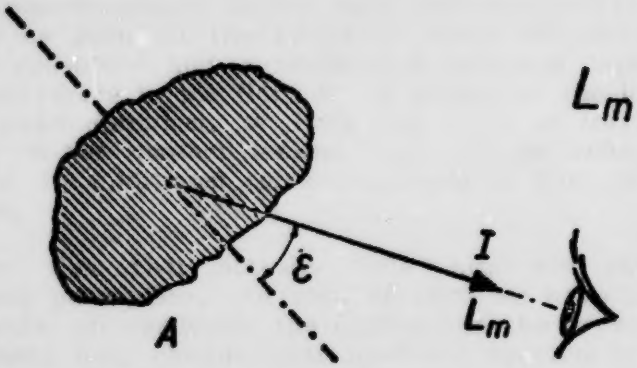
Eclairement E
Illuminance E
Beleuchtungsstärke E

COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

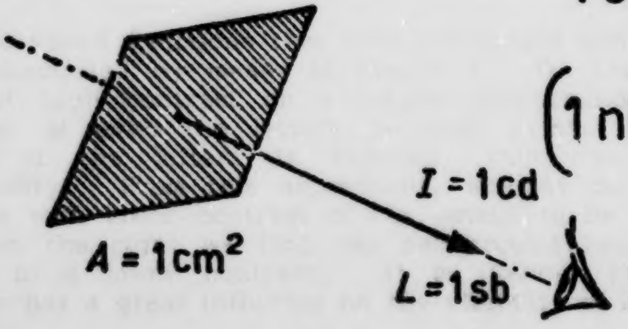
Fig.8



$$L = \frac{dI}{dA \cdot \cos \varepsilon}$$



$$L_m = \frac{I}{A \cdot \cos \varepsilon}$$



$$1\,\text{sb} = \frac{1\,\text{cd}}{1\,\text{cm}^2}$$

$$\left(1\,\text{nit} = \frac{1\,\text{cd}}{1\,\text{m}^2}\right)$$

Luminance L

Luminance L

Leuchtdichte L

THE HUMAN EYE AND ITS CHARACTERISTICS

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School of Optometry
University of Waterloo

Visual perception, or what we call seeing, is mediated by basic visual functions that are characteristics of the human visual system. With respect to the matter, to be discussed in this symposium, I would like to exemplify the basic visual functions by the contrast sensitivity and form perception that leads to that property we call visual acuity.

Even at the risk of being too elementary, I would like to use a cross section through the eye, as in figure 1, to explain what kind of influences we have to anticipate when dealing with the light stimulus that evokes the visual sensation. In the normal or emetropic eye, this means an eye that doesn't need any correction for its optical properties, the transparent cornea is the main refractive surface that images the object to be seen on the retina, a brain tissue containing the light sensitive receptors and a variety of neuronal layers. In case the corneal curvature is too flat, or too steep, or the longitudinal distance to the retina abnormal, or both, we have to correct for the optical error by either contact lenses, that change spherical shape of the cornea, or by additional refractive media in front of the eyes such as spectacles.

The light flux that actually falls onto the retina is essentially determining perception. In view of this, we have to consider that the ocular media, in particular the cornea and the crystalline lens, are not totally clear; but, change their total and spectral transmittance significantly with age. This point is of great importance, as the patients we normally find in hospitals are on average of higher age. Thus we have to design the lighting conditions in hospital accordingly.

The basic visual functions that form perception and contrast sensitivity can be discussed by means of Figure 2. On the left side we have letters of high contrast on a bright background which allows easy perception of even the letters in small print. In the centre the contrast of the letters is reduced, this obviously lowers their perceptibility. From this experiment, we may derive that perception decreases with lower contrast of the details to be seen. In the third column on the right we find the background luminance decreased in addition to a lower contrast. It is obvious that the background luminance has a great influence on the visibility of letters.

By definition, form perception or visual acuity is expressed as the reciprocal of the angle measured in minutes of arc of the detail. In case of the letters the thickness of the bars are used and expressed as the reciprocal of angular subtense. In case of a Landolt ring it applies to the opening having the same dimension as the thickness. The visual acuity is unit if the letter thickness or the opening of the Landolt C, which can be just detected, measures one minute of arc. In figure 3 the function of visual acuity for an object of high contrast is shown versus the luminance of the background. The lower branch with very low acuities due to pure rod or night vision is followed by a rising portion indicating that acuity is steeply increasing with higher luminance levels. It finally approaches a maximum that is determined by the optical aberrations of the eye and the resolving powers of the retina itself.

The experiments carried out by Koeing in the 1880's were partially repeated with different criteria, and extended to various contrasts of the objects. What we learned quantitatively from figure 2, this is reduced visibility with lower contrast, can be read quantitatively from figure 4. At a constant background luminance the visual acuity drops drastically when we lower the contrast from .9 which equals black print on white paper to .12, a faint gray. A horizontal line drawn through the family of curves shows that reduced contrast can be compensated by an increase of luminance of the background to achieve the same acuity. This is depicted separately in figure 5, in which the necessary contrast of the Landolt C required to achieve a visual acuity of S = 1 is plotted versus the luminance. Reducing the contrast, for example from a black letter C = .9 to faint gray C = .12, would require roughly a ten times higher luminance level in order to preserve that level of visual acuity.

When looking at basic visual functions we have to consider the stimulus at the retina while the luminance as plotted on these graphs refers to the physical stimulus outside the eye. The functions shown so far were obtained with relatively young observers and cannot be generally applied to any age population. This is evident from figure 6 showing the spectral transmittance of the cornea for different age groups. We notice that with age the cornea becomes more yellowish because of the reduced transmission of the short wavelength part of the spectrum relative to the red portion. Furthermore the total transmittance reflected by the level of evaluation of the dotted curves is receding with age. A similar phenomenon can be observed in the crystalline lens. Figure 7 adopted from Lit. 2, shows isolated lenses of various ages. In the first row depicting lenses of 6 months through 12 years we hardly recognize a yellowish tint. This however, is clearly detectable in the second row showing a 25, 47 years and 60 years old lens and finally in the third row that of a 70, 82 and 91 years old person. In the last row we have examples of cataractous lenses on the left side a strong nuclear cataract in the centre a cortical cataract and finally a combination of both on the right. There is not much difference between a lens of 80 or 90 years to a cataractuous one, we can hardly differentiate them. This implies that people of high ages are filtering the light yellowish and the transmission drops down drastically which restricts the incident light flux onto the retina. In the form of a diagram the total transmission of eye media looks as in figure 8 where findings of Blackwell(3) are compared with other authors showing clearly that at the age of sixty the total transmittance of the eye media is down to approximately 45%, compared with the reference group of a 20 to 30 year old observers.

Aside from the reduction of the light flux reaching the retina due to the lower total transmission, we observe a second effect impairing vision with age. The light passing through the eye media is also scattered and produces a veil of straylight that superimposes on the retinal image and reduces the contrast of the object causing lower visibility. So we have the combined effect of reduced transmission and a reduction of internal contrast due to straylight to occur in the elderly eye. The main sources of straylight are the cornea and the lens as indicated in figure 9. The straylight is marked by arrows. As the scattered light increases with age we may understand why the sensitivity to glare increases proportionally, which has a great bearing especially on driving under night time conditions. With respect to hospital lighting we have to place emphasis on the fact that high luminances occurring in the field of view which could act as glare sources should be avoided. No direct view into light sources of high luminance should be possible.

A combination of both effects that of reduced transmission of the ocular media and that of the increasing straylight is shown in figure 10 and reveals the disadvantage elderly people have compared to the reference group of 20 to 30 years in order to develop a form perception for visual acuity S = 1. We learn from this graph that even for the high contrast of C = .9 we have to demand at the age of 70 a luminance level of approximately 3.5 times in order to compensate for the natural changes occurring in the eye media.

In summary, we may conclude from the basic visual function of visual acuity, which we have reviewed, that luminance levels have to be provided to allow for a minimum of a form perception for people of all ages.

Further to that, we should definitely avoid glare sources to occur in the field of view which are causing straylight in the eye and are impairing vision in young and even more so in older eyes. This entails the necessity to place emphasis on geometrical aspects, for example, a patient should not face bright windows or be allowed to look directly into high luminances such as luminaires with no diffusion screens.

Needless to say that similar aspects apply also to the physician who has to examine people including the aspect of colour rendering. That should be high in order to allow the physician to judge on the patients complexion for example.

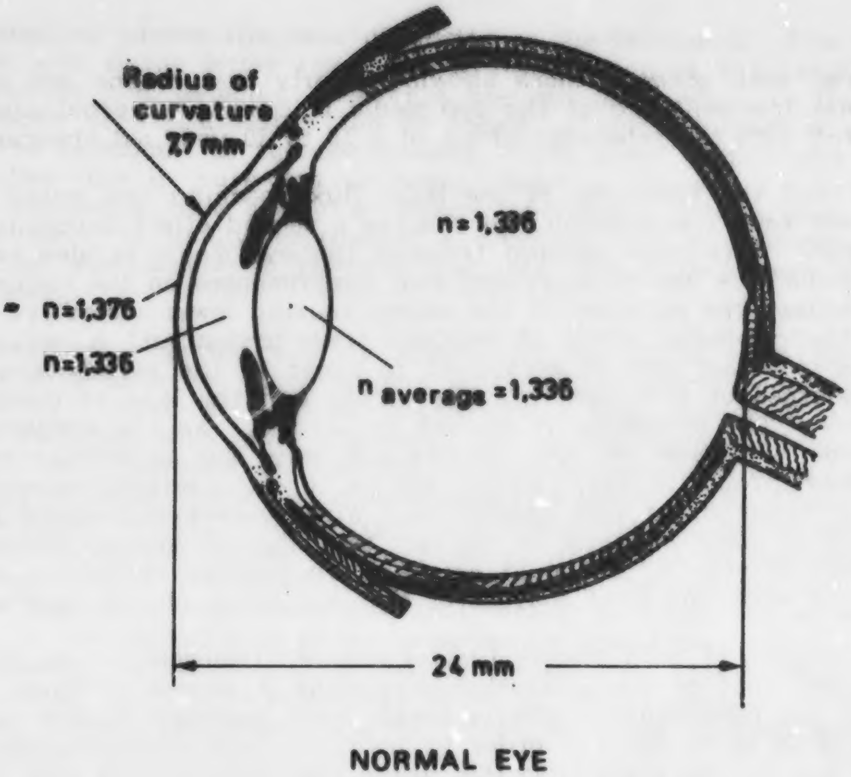

Radius of curvature 7,7 mm
n=1,336
n=1,376
n=1,336
n average =1,336
24 mm
NORMAL EYE

Fig. 1. CROSS SECTION THROUGH THE NORMAL, EMETROPIC EYE

Note that the average refractive index n refers to that of the crystalline lens.

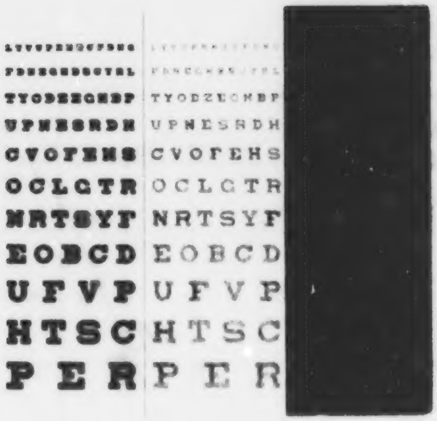

TYODZECHBF
UPNESRDH
CVOFEHS
OCLGTR
NRTSYF
EOBCD
UFVP
HTSC
PER

Fig. 2. INFLUENCE OF CONTRAST AND BACKGROUND LUMINANCE

Demonstration of the influence of contrast and background luminance on the visual acuity of the eye. This can be clearly seen that reduced contrast and lower luminance levels of background decrease visibility of the letters.

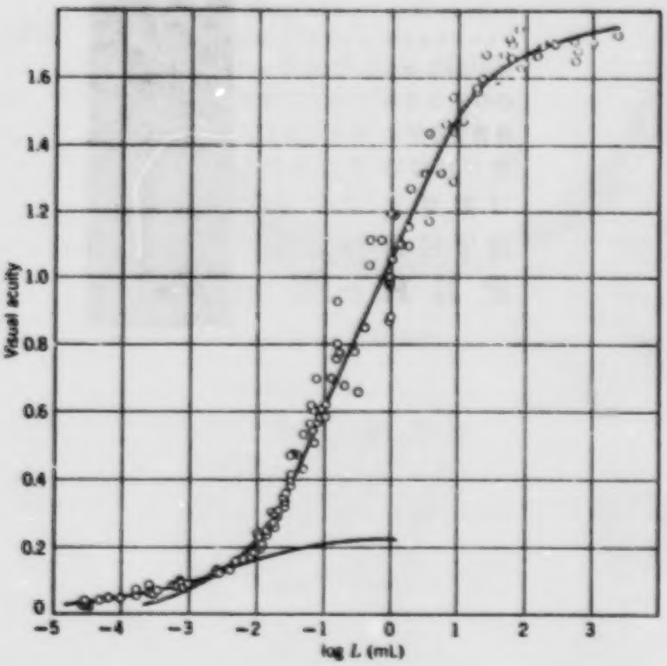


Fig. 3 RELATION BETWEEN VISUAL ACUITY AND ILLUMINATION

König's data for the relation between visual acuity and illumination, as replotted by Hecht (1934). The shallow curve for the lower limb of the data is an equation for rods, whereas the upper curve is for cones. The task is one of recognizing the orientation of a hook form of test object.

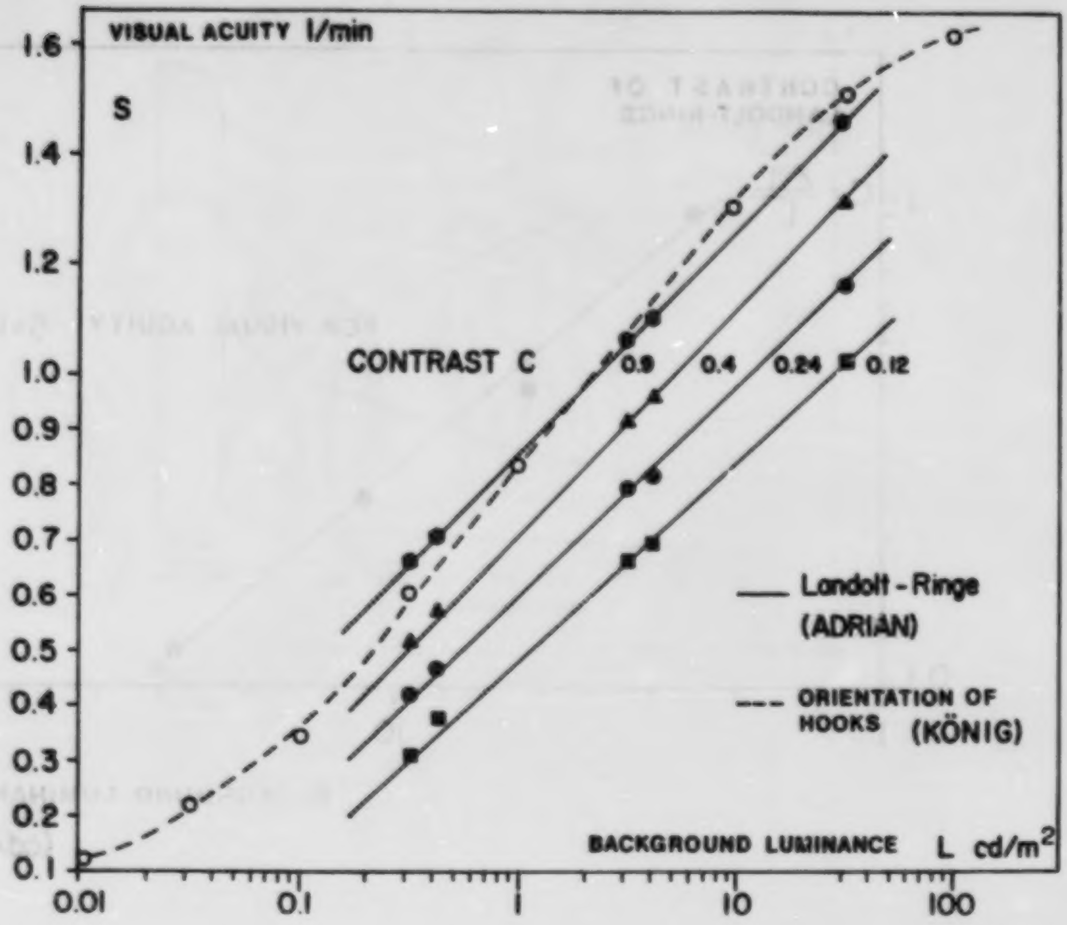


Fig. 4. BACKGROUND-LUMINANCE AND CONTRAST OF THE OBJECT

Visual acuity as a function of background luminance and contrast of the object. König obviously carried out his investigation with objects of high contrast.

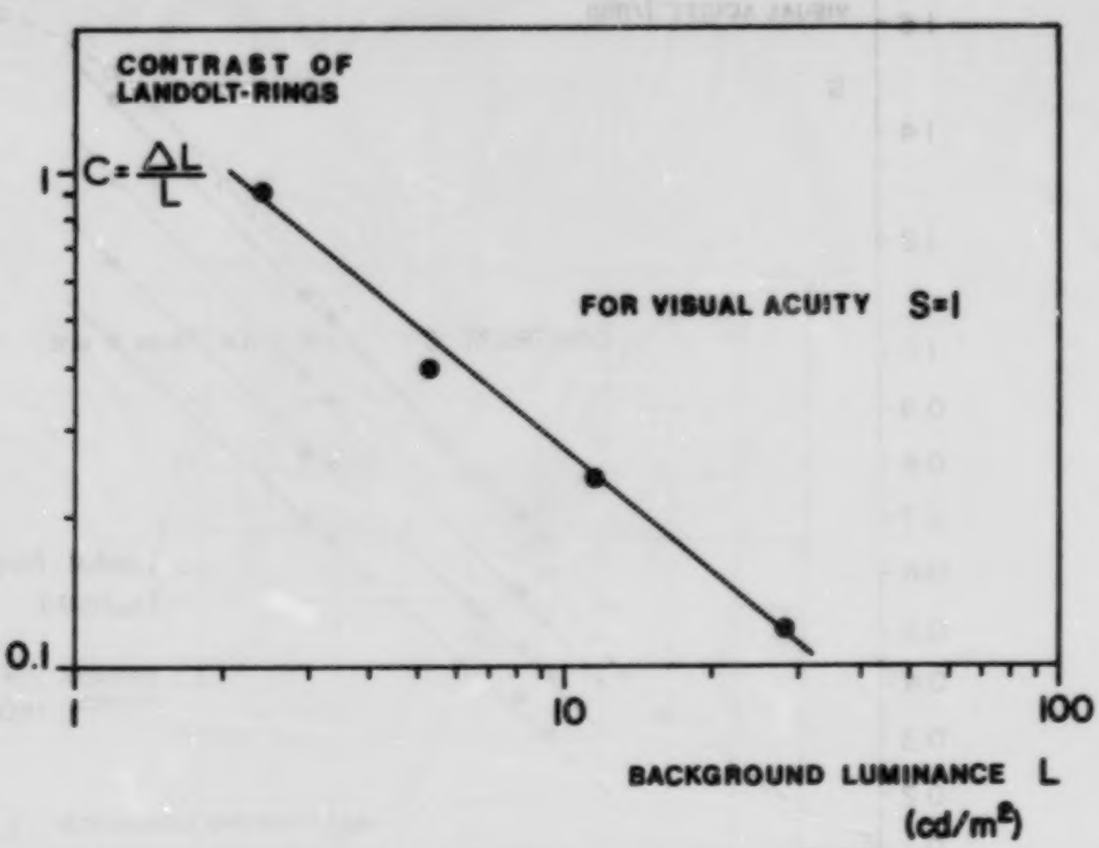
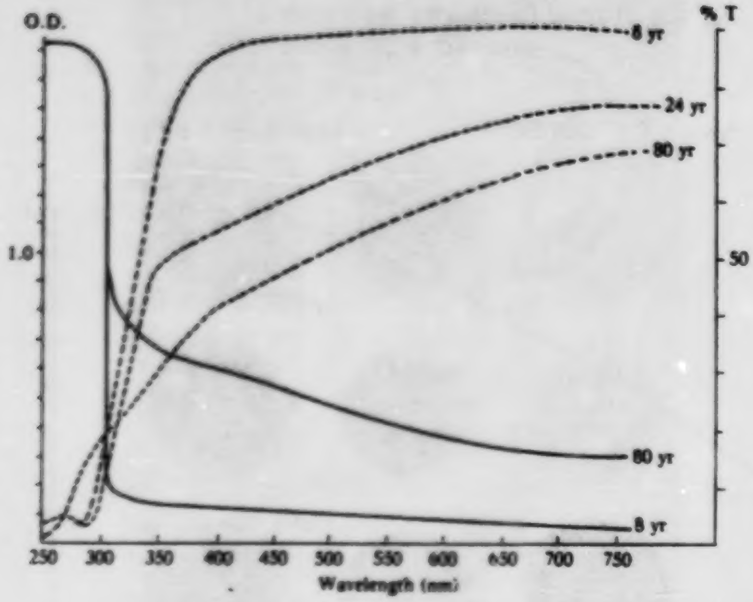


Fig. 5. CONTRAST OF LANDOLT C'S BACKGROUND LUMINANCE

Necessary contrast of Landolt C's and background luminance to achieve a visual acuity of S = 1. The data based on young observers (after Adrian).



Absorption (solid line) and transmission (dotted line) of the human cornea.

Fig. 6. RELATION BETWEEN ABSORPTION AND TRANSMISSION

Absorption (Solid line) and transmission (dotted line) of the human cornea of different ages. The figure was adopted lit. 2.

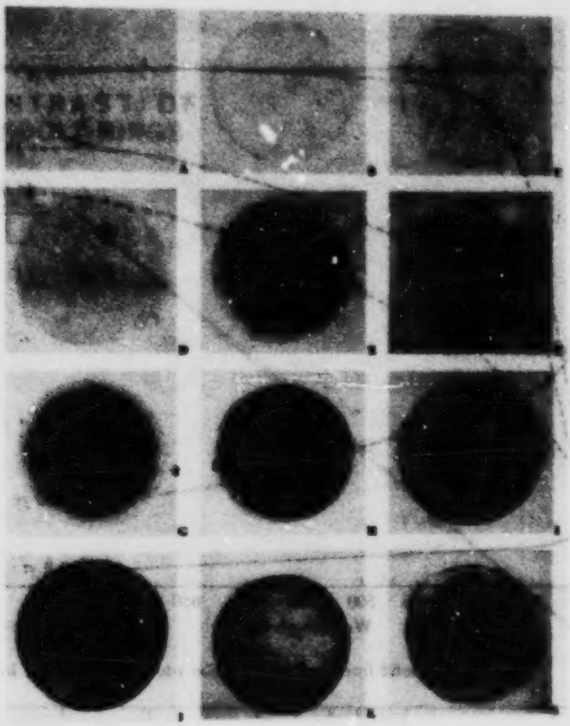


Fig. 7. THE INCREASING YELLOW-BROWN COLOUR OF THE NORMAL LENS AS IT AGES (AFTER LIT. 2).

(A) 6 months (B) 8 years (C) 12 years

(D) 25 years (E) 47 years (F) 60 years

(G) 70 years (H) 82 years (I) 91 years

Plate J shows an example of a brown unclear cataract (70 years old lens). K depicts a cortical cataract of a 68 years old person and L a mixed unclear and cortical cataract of at 74 years.

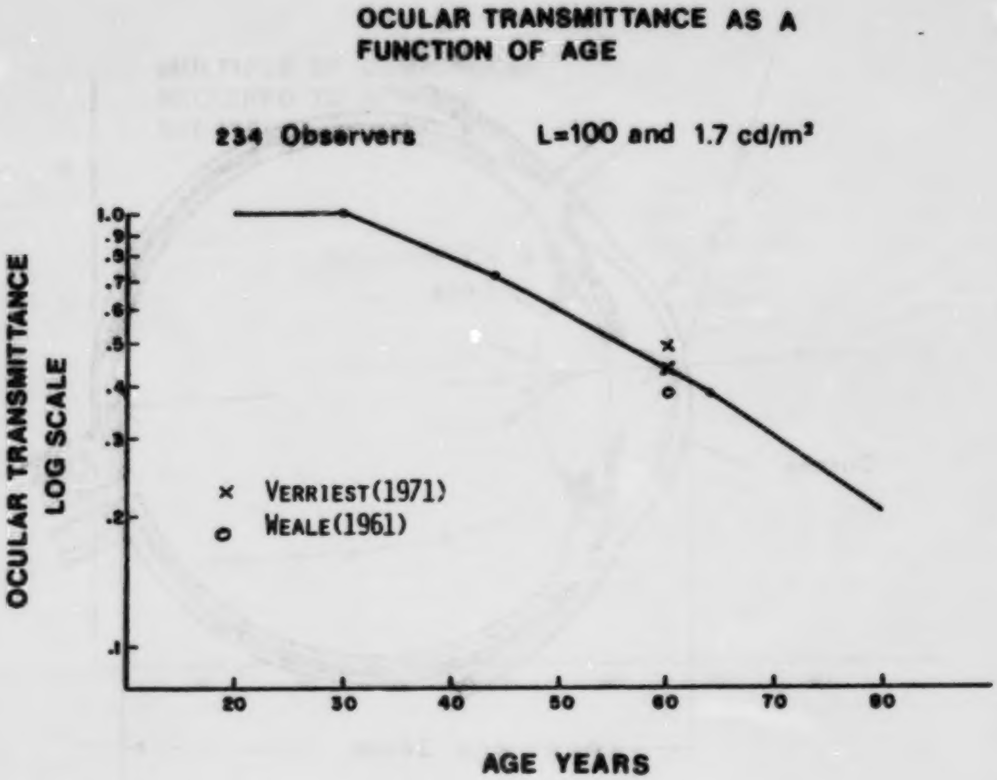
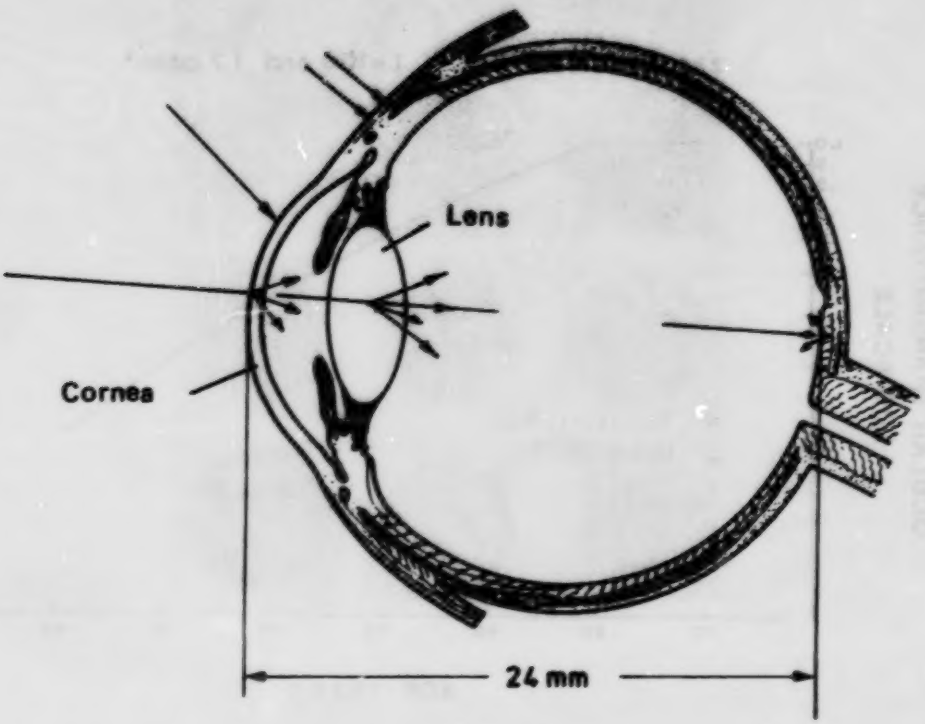


Fig. 8. OCULAR TRANSMITTANCE

Blackwell's data on ocular transmittance obtained from 234 observers at two different luminance levels in comparison with some data reported by Verriest and Weale (after Lit. 3).



NORMAL EYE

Fig. 9. PRINCIPLE SOURCES OF STRAYLIGHT OCCURRING IN THE EYE MEDIA

In eyes with low pigmentation we could also have some light entering the eye outside the pupillary entrance.

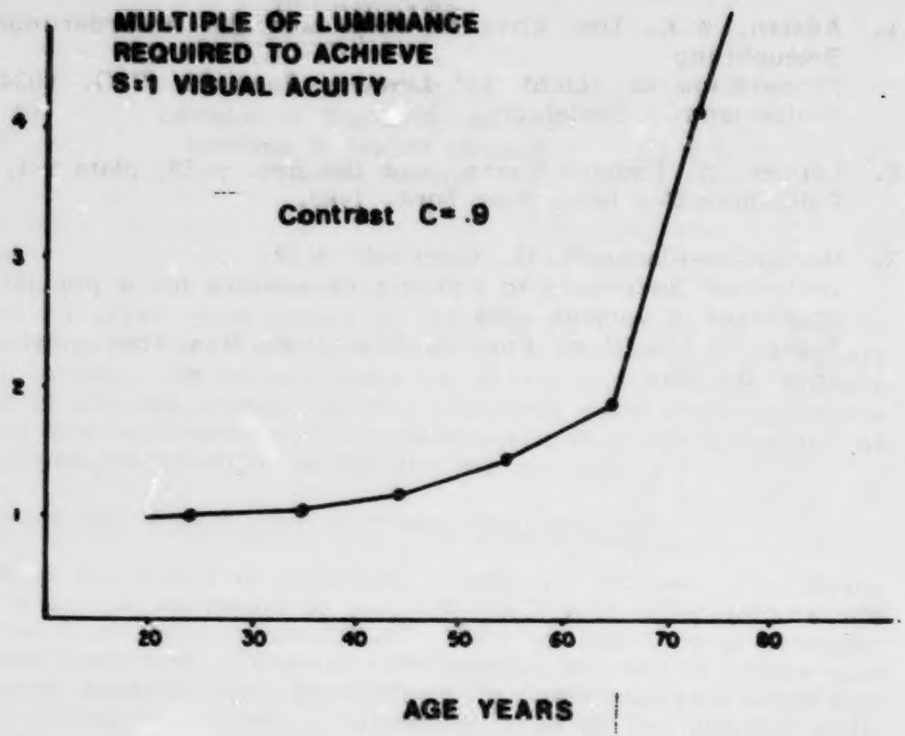


Fig. 10. LUMINANCE TO ACHIEVE A VISUAL ACUITY OF S = 1

Necessary luminance to achieve a visual acuity of S = 1 for different age groups for high contrast objects after Adrian (Lit. 1). The data are derived from the basic visual acuity function with regards to reduced ocular transmittance and scattered light that reduces the retinal contrast of the object to be perceived.

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VISUAL PERFORMANCE PARAMETERS

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Introduction

Probably in no other environment is lighting more important than in hospitals. Many of the tasks performed by staff members are highly visual and, further, the consequences for errors and time may literally be a matter of life and death. In this talk some very simple questions about seeing are addressed and the parameters that affect seeing, as well as some possible solutions in lighting are discussed.

The Importance and Measurement of Visual Performance

Why do people put lights in hospitals, schools or offices? The simple answer is to enable occupants to see. A variety of other factors will determine the final lighting installation, such as initial costs, energy, flexibility and aesthetics. However, the ultimate success or failure of a lighting system depends upon its ability to provide adequate conditions for seeing. This, of course, is especially true in the hospital environment. Many of the activities undertaken by the professional staff involve highly visual tasks, and the penalties associated with poor visibility may literally be death. Consequently, it is imperative that the lighting specialist provide adequate seeing conditions for the staff members.

What factors affect our ability to see? For lighting application there are two primary factors to be considered for seeing, brightness and brightness difference. These are the visual factors primarily affected by the lighting specialist. This is not to say that these are the only visual factors affected by the lighting specialist, nor is it to say that these are the only factors important to the visual system. Rather, these are the factors in lighting application most influential to seeing and, therefore, they are the ones emphasized here.

How do we measure seeing? One typical way employed in studies of the visual system is to find the minimum perceptable brightness or minimum perceptible brightness difference. These procedures are known as threshold tests. Like the threshold in a doorway is the transition point between two rooms, visual threshold is the transition point between two visual states, visible and invisible. Thus, threshold tests are all-or-none measures; either the task is seen or it isn't.

Such threshold tests of seeing are very reliable and sensitive to changes in the state of the visual system. Therefore, they are quite important in evaluating its behavior. However, they have the distinct disadvantage for lighting application of being unrealistic. That is, there are very few threshold tasks in the actual lighted environment. Most tasks can be seen, but the question for the lighting specialist is, "Can they be seen better"?

How, then, can we measure better seeing? One way is to simply ask people if they see better when changes are made to the lighting system. Anecdotal reports from people performing visual tasks, especially highly critical visual tasks like watch repair or surgery, indicate that brighter tasks are seen better than dimmer tasks. Physicians, on the whole, strongly request more light on the task. Such reports have naturally influenced recommended illumination levels. In fact, some of the highest levels of illumination that have been recommended have been for hospital tasks. These anecdotal reports are very important, but we need to measure "better seeing", or visibility, more objectively.

One way that we at the National Research Council have used to measure visibility is through recordings of subjects' speed and accuracy at reading numbers. We asked people to perform a numerical comparison task at various levels of brightness, or more technically luminance, and for various brightness differences, or contrasts, to see if their performance improved with these parameters. We found that, indeed, both speed and accuracy increased with luminance and contrast. It is interesting to note, however, that the rate of improvement in speed and accuracy with luminance was different depending upon the contrast of the task detail. Increasing task luminance has a greater effect on low current material than on high contrast material, as seen in figure 1. By looking at many combinations of luminance and contrast we can obtain a response characterization of the visual system for speed and accuracy as seen in figure 2. Such a visual performance model can enable the lighting specialist to quantitatively evaluate how lighting parameters affect the speed and accuracy of seeing.

Lighting Parameters Affecting Visual Performance

Lighting Quantity

The lighting specialist must consider two general aspects of lighting systems as they affect visual performance. Perhaps the most obvious is brightness level, or lighting quantity. Fortunately, the visual system is designed to maintain visual constancy as evident by the large plateau in figure 2; it is only at the very lowest luminances and contrasts that performance deteriorates dramatically. To a large extent, then, the visual system is capable of seeing well over a large range of luminances and contrasts. Two points should be kept in mind, however. First, as was mentioned above, lowering luminance has a greater effect on low contrast material than on high contrast material. Consequently, it is inappropriate to discuss light level by itself without some consideration to the contrast of the task being illuminated. Many tasks associated with the hospital environment have low contrasts. Examining details on x-ray films, inspecting pathological tissue or organs, and even reading pencil markings on charts require seeing low contrast. Under conditions where one may experience low contrasts, special consideration should be given to the brightness of the task. Second, even with high contrast tasks, performance continues to improve with higher luminance. In life and death situations even a fractional improvement in the physicians speed and accuracy may be important. If I were having an operation, I would hope that the lighting specialist had not tried to save some money on energy for his client by reducing illumination levels in the operating room.

Lighting Quality

The other general aspect of the lighting system that must be considered is lighting distribution. This is sometimes referred to as lighting quality as opposed to lighting quantity, or brightness levels just discussed. Most times lighting quality is more important than lighting quantity in ensuring good seeing conditions in the lighted environment. Poor lighting distribution can reduce an otherwise high contrast task below visual threshold. In other words, some tasks can be rendered invisible with improper lighting design. There are three related phenomena associated with the brightness patterns provided by the lighted environment that reduce visibility and should be considered by the lighting specialist, veiling reflections, luminous uniformity and direct glare.

Veiling Reflections

Veiling reflections are produced by the light reflected from surfaces, and they reduce or eliminate the physical contrast of task details. Thus, veiling reflections impair ones ability to see these details. Lighting geometry, or the angular relationship between the viewer and the light sources, is very important for controlling veiling reflections. Consideration must be made both of the placement of windows and luminaires and of the likely viewing position of the occupant. Specifically, care must be taken to prevent illuminance delivery from mirror angles to the occupant's line of sight. The most promising solution for poor lighting geometry is the introduction of flexibility into the lighting design. Many times the lighting specialist does not know how occupants will be oriented in the final working environment so it is difficult to place luminaires or windows in locations that will not produce veiling reflections. If the light source or the occupant can be moved easily to avoid veiling reflections, then the lighting specialist will more likely have a successful lighting system in this regard.

Solutions to this problem of veiling reflections are not only found in the lighting geometry (although this is usually the most effective solution), but many times solutions are also found in what is being lighted. Matte surfaces, like newsprint or typing paper, are very good at limiting veiling reflections, even at the worst angles. Word processing and computer screens can be fit with a fine mesh that reduces the reflected light from these mirror-like display terminals. Even though these task related solutions usually lie outside the professional responsibility of the lighting specialist, they should be considered as alternatives to a strictly lighting solution of veiling reflections.

Luminous Uniformity

The uniformity of the luminous distribution is also important to ensure high levels of visual performance. As noted above, visual performance improves with the brightness difference of the task detail, but if the brightness differences outside the immediate task area are not relatively small, then visual performance will be impaired. In other words, if areas within the visual field near the task area are darker or brighter than the task itself, ones ability to see well will be reduced. This visual effect is not particularly large compared to that which can be produced by veiling reflections mentioned above or direct glare described below. Here again, however, if the best possible seeing conditions are required, as in surgery, luminous uniformity should be emphasized.

Luminous nonuniformities in the actual lighted environment are usually encountered in two, sometimes related, situations. The first situation is associated with directional lighting from, say, windows or with task lighting for reading, surgery or fine inspection. Many times a bright, small "pool" of light is produced in the task area, and there is lower or no other ambient illumination in the room. Under nonuniform luminous conditions one may experience a drop of visual performance. As with low illumination levels, luminous nonuniformity will affect seeing task details of low contrast more than those of high contrast. The second situation is associated with word processing and computer screens. In an attempt to reduce veiling reflections from these screens, occupants will many times turn off the overhead lights and cover the window blinds or curtains. This may be a good solution for dark screens, but relatively bright screens in an otherwise dark room will not be conclusive to optimum visual performance. Task lights may also be introduced into the darkened environment with word processor and computer screens in order to read printed material. Here again, visual performance will not be at its highest due to the large differences in brightness in the visual field. The lighting specialist interested in ensuring optimum visual performance should consider providing luminous uniformity, even though this may imply more expensive hardware, higher energy costs, or poorer aesthetic qualities.

Direct Glare

The last issue to be discussed with respect to lighting distribution is direct glare. Glare is like luminous nonuniformities except glare sources are very much brighter than the task area. Glare can be produced by both natural and artificial light sources and can be a serious problem for both the staff member and for the patient in the hospital. Unlike veiling reflections which affect the physical contrast of the task details, glare reduces the contrast of the task detail in the eye itself. Anytime a light source is in the field of view glare will occur; the brighter the light source and the closer it is to the task being viewed the larger the deleterious effects from glare in reducing apparent contrast. Like veiling reflections, then, lighting geometry is very important with glare. Hospitals, perhaps present a unique problem in lighting geometry, particularly with regard to glare, because of the prone position assumed by patients. Many times a light source will be in an ideal location for the physician, but because the patient is on his back looking up into the lights he can experience a great deal of glare.

It is probably impossible to have a lighting system that will simultaneously be satisfactory to the staff member and to the patient, and certainly the lighting specialist must bias the lighting designs to favor the staff member performing his duties. However, it should be remembered that staff members do not deal with the patient throughout the day and night. Staff members attend patients, perhaps, only a small fraction of this time. Consequently, it seems imperative to incorporate flexible lighting systems that can be moved to less offending areas or simply can be turned "off" or "on" at will. Simple dimming or conventional onoff switches convenient to the patient may be quite effective for reducing glaring light from the luminaires not being used by staff members. Even simple window blinds can be considered a flexible lighting control for glare.

Summary and Conclusions

Lighting is for seeing. Visual performance, as measured by speed and accuracy, is an important part of seeing in the hospital environment. Both lighting quantity and lighting quality are important for seeing, and with an understanding of the effects that these lighting parameters have on visual performance, problem areas in lighting can be identified and practical solutions established.

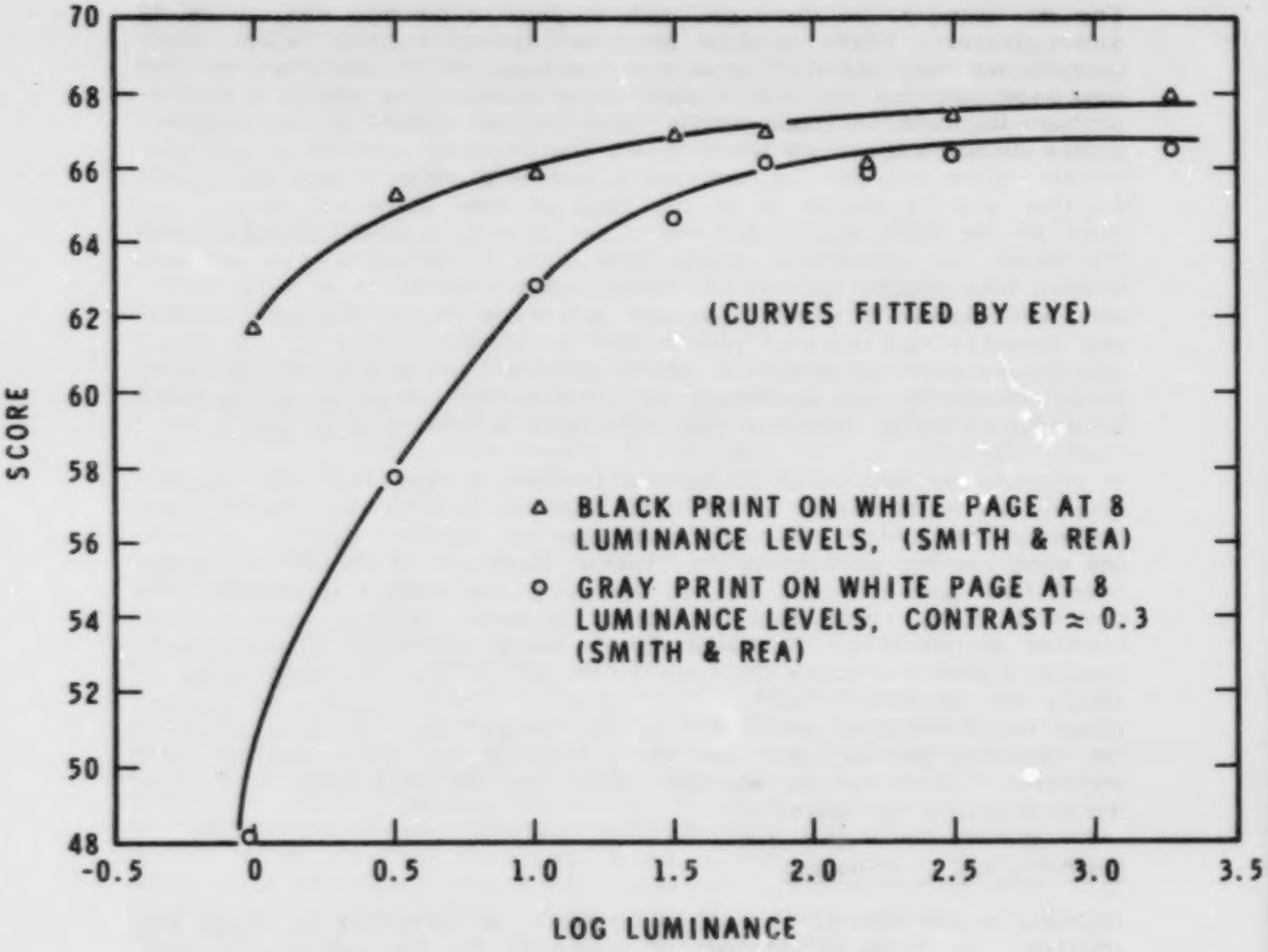

Fig. 1. RELATIONSHIP OF SCORE TO LOG LUMINANCE

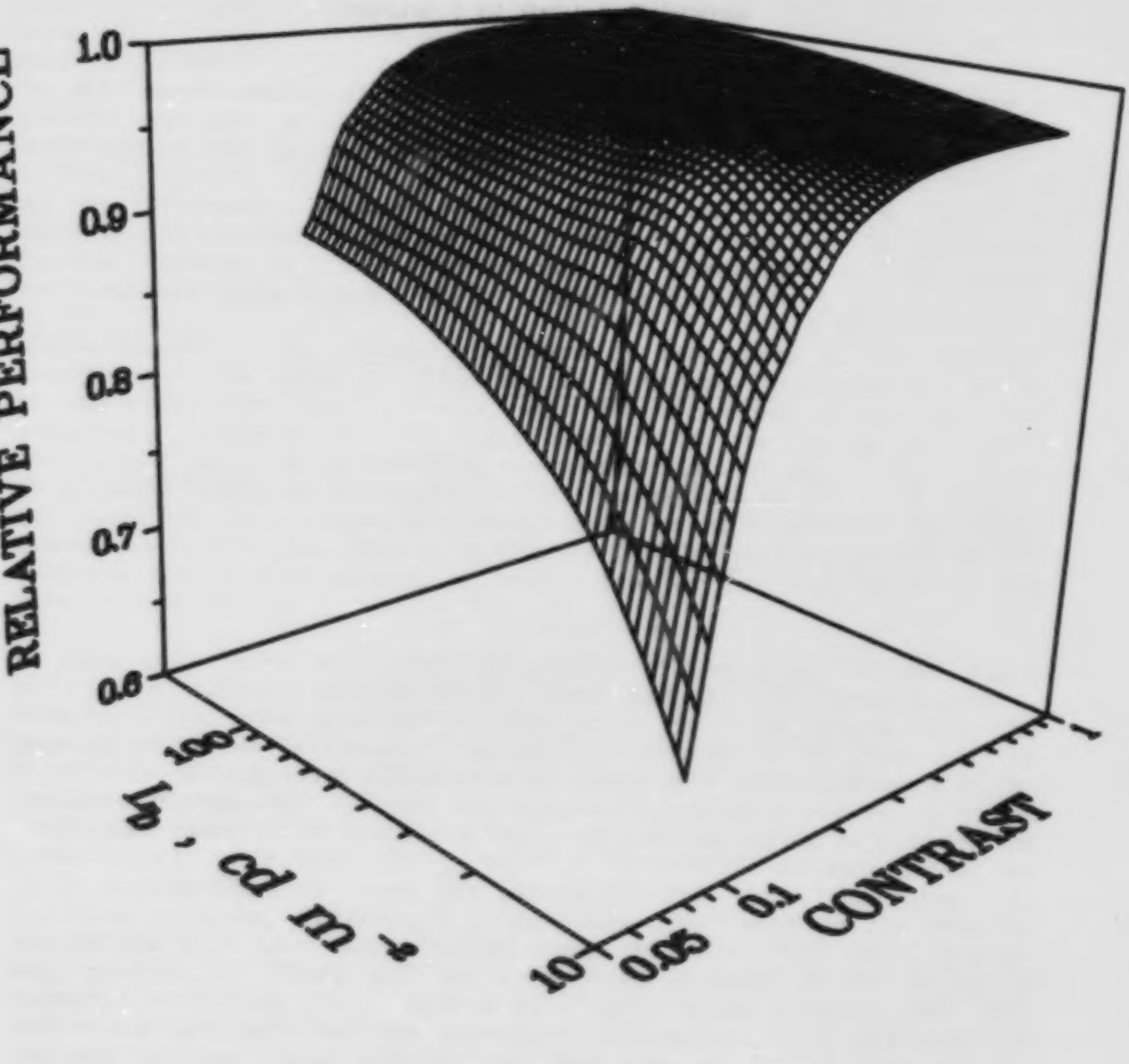

Fig. 2. RELATIONSHIP OF RELATIVE PERFORMANCE AND CONTRAST

PSYCHOLOGICAL ASPECTS OF VISUAL ENVIRONMENT

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Visual Laboratory
Department of Psychology
University of British Columbia

In this short review of the environmental problems encountered by a psychologist who is also a visual scientist, emphasis is placed on the contribution that laboratory studies can make to a field problem.

As the interaction between vision and the environment is rather a complex phenomenon, a number of the eye's functions must be discussed in the context of their contribution to perception of the visual environment. This inquiry will be limited to five areas:

These include: (1) Dark adaptation or the study of the absolute sensitivity of the eye, (2) The relative luminosity functions in relation to the recognition that the eye, with its two types of detectors, is selectively sensitive to the light energy of the visual spectrum, (3) Colour vision or specifically, the contribution of cones, functioning at photopic levels of adaptation, to the perception of the environment, (4) Glare or the problem of uneven levels of high ambient adaptation intensities in the environment, and lastly (5) Contrast sensitivity or the temporal and spatial aspects of vision that are so important for the perception of form.

In each case there is a brief description of the area involved which includes a summary of the known facts and derived generalizations. However, the main purpose of this paper is a departure from the generalizations of textbooks; that is, its purpose is to point out the importance of individual differences in vision and their relevance to the problems discussed. Behind the generalized smooth curves of visual functions presented in textbooks lies a host of individual responses that differ significantly from the known curves to such an extent that we might regard them as being the exceptions that break the rules. In the first instance, differences in response occur even in the selected populations that have been studied (most of whom were young university students). They will be even more extreme if our study is extended to include the variations in a given visual function with age, and there are also extreme deviations concomitant with the acquired changes in the visual system that are due to the physiological or pathological effects of a disease. The sum of all these variations leads us to question the relevance of any generalized findings in a real situation such as a hospital population, an institution for the aged, or, say, a school or a prison environment (to mention only a few), for each of these environments will have specific "viewing populations" that will be markedly different from the generalized norms.

Dark Adaptation

The human eye deals with extreme changes in light intensities by a process known as adaptation. 'Light adaptation' occurs when the eye 'adapts' from low to high levels of light intensities in the environment, while 'dark adaptation' occurs when the eye is exposed to minimum amounts of light after previously being exposed to high intensities. Light adaptation is rapid but difficult to measure and some of the more complex problems related to uneven levels of high ambient adaptation intensities will be discussed when we talk about glare.

Here we will discuss dark adaptation which is a slower process and therefore more easily measured. Studying dark adaptation thresholds is also one way of measuring the absolute threshold sensitivity of the visual system. The traditionally quoted dark adaptation curve has distinct cone and rod segments, in which the cone segment first shows a steep drop in adaptation with time then levels off after 5 minutes, while the rod segment drops less steeply but continuous to fall for at least another 10 minutes. The point where the two segments meet on the curve marks the changeover from mostly cone function (photopic vision) to mostly rod function (scotopic vision). Individuals differ in their rates of cone to rod adaptation.

There is a consensus of opinion that these absolute achromatic thresholds not only vary in a young population, but also become raised progressively with increasing age, to the extent that the difference between a sixteen-year-old and a ninety-year-old is about two log units, (that is, a ratio of 1-100). Further evidence has accumulated that various eye diseases and systemic diseases of the body affect dark adaptation function and accelerate the aging effect so that, for example, a sixty-year-old with a specific disease might have losses greater by two or three log units than members of his age-equivalent control group. In this case, the total increase in threshold value in comparison with young subjects would be 4-5 log units, or a ratio of 1-100,000. There are still no age norms in chromatic adaptometry, but, from the evidence available so far, it appears that foveal losses are greatest for short wavelengths, while peripheral retinal losses are greatest for long wavelengths.

This information is important in the applied field, especially now that it is fashionable to know the minimum luminance levels necessary for each situation in order to conserve energy and information about the accelerated aging effect in patients and the consequent loss in absolute threshold sensitivity is very important for hospitals and institutions for the aged.

Relative Luminosity Function

In addition to the aspects of hue and saturation, total visual experience also involves the perception of brightness and luminance. Here it is important to realize that the eye is a selective detector, and that it is not equally sensitive to all wavelength in the visible spectrum. Since there are two types of detectors of radiant energy in the eye (rods and cones), there are at least two types of sensitivities which depend upon the overall adaptation level of the visual system. These sensitivities are referred to as photopic when the eye is adapted to high intensities of light, (e.g., during daylight which results in the so called photopic-relative luminosity curve (V) and scotopic when the eye is adapted to minimal amounts of light, (producing the so-called scotopic-relative luminosity curve (or V')). A third condition gives rise to mesopic vision at adaptation levels where both cones and rods can contribute to the luminosity sensitivity. As a consequence there are corresponding changes in the apparent brightness of surface colours with changes in ambient adaptation levels (the so-called Purkinje Shift).

Again most of the data on the two luminosity functions has been collected on young people, and the traditionally-quoted calculations of luminance values of illuminaires are based on such data. The same applies to the use of photometers or light meters that are calibrated to mimic the sensitivities of young observers. However, for some time now it has been known that even among young observers, there are large individual differences in these V values, and very little work has been done on aging or on those with clinical conditions. Yet many diseases which lead to acquired visual losses are also associated with changes or shifts in the V curves. For example, among those whose losses resemble congenital protan colour deficiencies, the peak of the photopic V curve is progressively displaced towards the short wavelengths. Certain diseases and the aging processes lead to a Purkinje shift at much higher levels of light adaptation than would occur among young observers, and thus ultimately leads to the so-called "scotopization" of the relative luminosity function. The result of this is that, at photopic levels of adaptation, vision becomes mesopic or even scotopic among those with large losses in brightness sensitivity, that is, it is devoid of colour and there are changes in the relative brightness values for the different wavelengths (or hues). For example, under these conditions blues, blue-greens, and purples become brighter than oranges or reds. Note also that the relative luminosity function curve does not provide a complete picture of such age changes, since it does not tell us about absolute losses.

This leads us to important practical implications. Situations involving decisions about the light levels required by older people and by hospitalized patients each require their own special solution, and here glare problems, colour, and luminance detection tasks are particularly relevant. Note that not all differences between the concepts of 'luminance' and 'brightness' have been resolved, and further elucidation is needed, and recently, objections have even been raised that the original relative luminosity values on which the C.I.E. standard V curve is based are grossly out of line at the blue and of the spectrum.

Colour Vision

In laboratory studies involving a young, very select population, it has now been established that the colour mixture ratios of a random population are normally distributed around a modal value, and follow a Gaussian curve, while the distribution for colour discrimination ability is skewed, with the majority of subjects showing good discrimination, and progressively fewer having poor discrimination. However, the moment we go away from such close-knit populations, we become aware of large individual differences in deficiencies. These arise from many factors, some hereditary, some acquired. About 10% of males (1% of females) have inherited deficient discrimination, and age also affects the ability to discriminate, both during pre-pubescence and senescence. This is especially true of the older groups, where the incidence of good discrimination rapidly decreases. Of course, there are also the acquired deficiencies that are the result of systemic or eye disease. Only between the years of 16 and 35 is colour discrimination at its best, and only normal young observers can experience the enormous number of colours in their environments. All others perceive less because of losses or changes in discrimination. It is hard to say what proportion of the total population will have good discrimination and how many will be less able to do this, but it is not exaggerating to say that between 5% and 10% of the acquired deficiencies can be as severe as any known congenital color defects, and affect males and females equally. Added to these deficiencies there are those brought about by age changes and the accelerated losses due to certain diseases, and recently it has also been noticed that even pre-clinical conditions have associated colour discrimination losses. Thus, today there is evidence to show that colour vision varies throughout the age continuum, that there are differences due to developmental factors among the young, and that there is deterioration with age due to factors involved in senescence. It is safe to generalize that the perception of the short wavelengths (i.e., the blue part of the spectrum) is the least stable, and is most affected by age changes.

The knowledge of the state of an individual's colour vision is very important in situations involving colour preferences, subjective and physiological reactions to colour, and in measuring retinal sensitivities within the visual field. It is also vital for illuminating engineers, architects, and designers, particularly since designers of hospitals, schools, and prisons are required to select colour schemes not on "a priori" grounds or on unproven assumptions, but on grounds which effectively fulfill their declared intentions. And in any age-related situation involving psychological or physiological variables, the individual's colour vision must first be ascertained since it might be one of the most important variables in determining psychological and emotional responses.

Thus, in any situation of complex interaction between a human observer and his colour environment, it is important that the state of the observer's colour vision should be clearly defined, not just in terms of the presence or absence of congenital colour vision deficiencies, but also in its normal deviation from the modal (or most frequent) values in a given population. It must be determined not merely to find its visual limitations, but so that in situations of choice, preferences, reaction, and emotional responses to the environment, we will know whether the visual system is deficient in terms of information processing at the sensory level, or whether it operates at its optimal levels, for we assume that any alterations in information processing will affect perceptual process constructs and information extraction, and hence responses to complex perceptual relationships.

Glare

When discussing aspects of the visual environment, it is important to talk about the problem of glare as it is obviously the greatest practical problem facing those who deal with such real environments. The existing theoretical model of glare, which is based on light scattering in the ocular media, can explain only a few of the phenomena associated with glare. It also conflicts with most of the experimental data, for if a decrease in task visibility is assumed to be due to the veiling portion of light scattered from the glare source, it is impossible to explain the beneficial role of background illumination since such light should also be scattered in the ocular media and should increase the veiling effect. Glare, then is that sensation produced when illuminance within the visual field is higher than the illuminance to which the eyes are adapted to the extent that annoyance, discomfort, or loss in visual performance or visibility may occur. In practical situations we distinguish two types of glare: (1) Discomfort Glare, where there is increased discomfort that does not necessarily interfere with visual performance and visibility, and (2) Disability Glare, where visual performance and visibility are reduced to a point where vision might not be possible. Street lighting at night is often quoted as a source of Disability Glare, while modern interior lighting is mainly responsible for Discomfort Glare. Early researchers were not interested in individual differences and age losses, and only in the late '30's' was attention drawn to the 'personal equation' when it was noticed that those wearing spectacles exhibited lower average contrast sensitivity, experienced greater discomfort from glare sources, and found sodium light more comfortable.

However, systematic studies of Discomfort and Disability Glare have clearly established that age affects visibility, recovery time and judgments of borderline between comfort and discomfort (BCD). Thus, the sensitivity to Disability Glare of older observers reduced their visual potential in comparison with young observers by a factor of 3 to 4 when levels of background luminance were equal and especially when lighting conditions were poor and luminances in the field surrounding the visual task were not uniform. Some claim that these reductions in the responses of older subjects may place critical limitations on how far task luminances can be reduced to conserve energy. Recovery time from exposure to glare also increases from 4 seconds for those in the forties to 8 seconds in the sixties. Studies of Discomfort Glare confirm the negative relationship between BCD and age, while other studies, particularly those on alcohol, show that in some subjects resistance to glare was lowered.

Contrast Sensitivity

This deals mainly with the temporal and spatial aspects of vision that are so important for understanding form perception. There are three approaches to this area of vision study. In visual acuity, maximum contrast between figure and background is utilized while, in methods involving the modulation transfer function, sinusoidal waveforms are used giving contrast variation from 0.5% to 100% in either spatial or temporal configurations. The basic causes for changes in acuity have been discussed already by Adrian. Here what we wish to stress is that, as early as the second half of the nineteenth century, age changes in acuity showing the steady decline in the number of subjects attaining normal acuity as age increases were already well-documented. The clinical losses in acuity are also well-documented, and can be attributed to cataracts, to many of the juvenile and senile degenerations of the macula, and to retinal pathology, and vascular changes, etc. It should be stressed, however, that even in their advanced stages many such ocular diseases show only minimal losses in acuity. Thus a Snellen Acuity of 1.0 or better does not necessarily indicate intact macular function and therefore does not alert us to a possible visual defect and therefore to the degradation of form in the environment.

A new approach through the study of modulation transfer functions, both in the spatial and temporal mode, provides us with a more extensive description of what is involved in form vision. Age affects the spatial contrast sensitivity functions, showing losses for higher spatial frequencies, and these losses seem to be due to factors other than a simple reduction in retinal illuminance (the main cause postulated for acuity losses). Again it has been shown that some ocular diseases lead to loss in the high frequencies while others affect the transfer functions of the low frequencies. Thus the evidence for the age effect on acuity, and especially on spatial contrast sensitivity, is firmly established, showing itself in the fact that older people are unable to see fine detail in a picture or, to put it differently, the perception of high spatial frequencies of form are age dependent.

There is less data on individual differences in the temporal and the so-called de Lange function. The critical frequency fusion (CFF) phenomenon was thoroughly explored in Europe in the 50's and 60's and there is a fair amount of data on aging and the retinal eccentricity and stimulus wavelength variables, that affect flicker. The CFF decreases with age; that is, older subjects perceive intermittent light as steady light at much lower frequencies of flicker than do younger ones. In an age population ranging from 20 to 70 years the reduction was from 40 to 30 Hz respectively.

Conclusion

It is hoped that enough evidence has been presented to show that generalized norms should be treated only as guidelines in lighting design. They only tell us where to start, but we must remember that each specific environment will require its own solutions depending on which particular population will be involved. For example, if lighting is designed on the basis of well known 'norms' then, in a hospital for the aged, we should be aware that the acuities of the older patients will be reduced and, in addition, they will experience losses in spatial contrast frequencies due to factors other than the pre-receptoral absorptions that reduce visual illuminance. They will be unable to experience the nuances of subtle colour schemes. Many will also function at mesopic levels in spite of adequate ambient levels of illuminance, and if these are raised to overcome such a disability, they will experience discomfort and perhaps even disability glare. The only positive aspect for such a population will be the fact that they will be less disturbed by flickers from fluorescent luminaries than those with normal vision.

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THE IMPACT OF COLOUR ON VISION COLOUR RENDERING AND COLOUR DISCRIMINATION IN HOSPITALS

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Abstract

The CIE and Munsell methods of specifying colour are explained briefly. The calculation of colour-differences and colour-rendering indices is discussed and applications to hospital lighting are suggested.

Introduction

In the time available for this talk I cannot deal fully with all aspects of colour science and its application in hospitals. Therefore, I will concentrate on a few important aspects and deal only very briefly with some of the others. I will start by reviewing some of the terminology and concepts that we use when talking about colour and will then go on to discuss how these concepts should be applied to hospital lighting design.

Physical Stimulus

The sensation of colour occurs when electromagnetic radiation of certain wavelenghts enters the eye. For most practical purposes, the visually effective spectrum may be considered to extend from 380 to 780 nanometres. (A nanometre, abbreviated nm, is 10^{-9} metres). Considerations of the emission of light from sources and its reflection, absorption, or transmission by objects must be made in terms of this physical stimulus (described by its spectral power distribution), but the actual sensation occurs within the observer. Thus it is wrong, strictly speaking, to use colour names when describing the rays of which the stimulus is composed, but for convenience we will often do so.

The sensation of colour depends, not only on the stimulus itself, but also on a host of other factors which as the nature of other stimuli in the field of view, the nature of other stimuli viewed in the recent past, the size and shape of the stimulus, whether it is moving or stationary, and many more. The human visual system is extremely complicated and not yet fully understood.

Photo-receptors

It is now known with a fair degree of certainty that the first stage in our colour vision system is the absorption of the stimulus by photoreceptors, known as cones, which are contained in an area called the retina at the back of the eye-ball. These cones absorb the electromagnetic radiation and produce nerve impulses which are passed to later stages of the system. There are three types of cone, each with a different spectral sensitivity. An estimate, based on experimental data, of the spectral sensitivities of the three types is given in figure 1. These three types of cone are sometimes described as blue, green and red cones because their sensitivities were originally thought to be in parts of the spectrum that usually look blue, green and red respectively. However this is now known to be not exactly true. The sensitivities are very broad and overlap considerably, and the actual sensations of blue, green and red occur only as a result of complicated neural processing involving the signals from all three cones.

It is important to recognize that each of the three cone-types is, in itself, colour-blind. It cannot distinguish between two stimuli of two different wavelengths if the ratio of the energies of the two stimuli exactly compensates for the different sensitivity of the cone to the two wavelengths. It is only because there are three types of cone, each with its own spectral sensitivity, that the system as a whole can distinguish between wavelengths, and hence possess colour vision.

Additive colour mixture

Because each of the three types of cone is colour-blind, and because there are only three types, it is possible to match the perceived colour of any stimulus by a mixture of three suitably chosen "primary" stimuli.

Imagine three projectors, each throwing a spot of light onto a white screen. One projector produces a red spot, one a green spot, and the third a blue spot, as seen in figure 2. Where the red and green spots overlap the spectral power distributions of the two stimuli are added together to produce a combined stimulus which appears yellow. Where the blue and green spots overlap the combined stimulus appears blue-green (sometimes called cyan) and where the blue and red overlap, the combined stimulus appears purple (sometimes called magenta). Finally where all three spots overlap the combined stimulus appears white. In fact by suitable adjustment of the amounts of the three primaries we can match almost any arbitrarily chosen test colour stimulus. The exact gamut of colour stimuli that can be matched depends on the choice of the three primary stimuli.

Metamers

What we are doing, when we make such a match, is equating the signals from the three types of cone. Although the test stimulus and the matching stimulus (the latter produced by mixing the three primaries together) are quite different in composition, the visual system cannot distinguish between them because the outputs from the three cones are the same for each of the stimuli. No amount of further processing can regenerate the information that has been lost, so the two different stimuli cause the same colour sensation. Such stimuli are called metameric stimuli, or metamers.

An example of metameric stimuli is given in figure 3. As is the case with all metameric pairs of stimuli the spectral power distribution curves cross at least three times in the visible spectrum. Stimulus 1 is an incandescent lamp. Stimulus 2 is a more complicated spectral power distribution which has exactly the same appearance to an average observer. Note that we cannot say exactly what colour the stimuli will appear, only that they will both appear the same under the same conditions. The actual colour will depend on many factors, as we have already noted. When we are fully adapted to it, an incandescent lamp appears white, but if we are adapted to daylight or to cool white fluorescent light, then an incandescent lamp appears very yellowish.

The spectral power distribution reflected by an object is the product of the spectral power distribution of the illuminating source, and the spectral reflectance factor of the object. Thus if two objects form a metameric match the match will usually be destroyed by a change of the illuminant. Similarly, because people vary a little in their colour-matching characteristics, a metameric match for one observer may be a slight mismatch for another observer.

The CIE System

The amounts of three primary stimuli required to match a given test colour provide a useful way of specifying the test colour. They are known as the tristimulus values of the test colour. In other words, the tristimulus values are the amounts of light in each of the three projector beams in figure 2. The International Commission on Illumination (known universally by the initials, CIE, of its French name, Commission Internationale de l'Eclairage) has defined a system of primaries so that everyone can use the same system and exchange information without confusion. Tristimulus values in the CIE system are always denoted by the letters X, Y, and Z. Specification of a colour stimulus by its X, Y, and Z values provides a description of the stimulus that is standard throughout the world.

If we increase the energy of a stimulus by a constant factor for all wavelenghts, the main change in the colour sensation evoked by the stimulus will be a change of brightness. Other aspects of the stimulus will, to a first approximation, not change. We call these other aspects the chromaticness of the stimulus. (Sometimes, these other aspects are called "colour", but more often the word "colour" is used to include both brightness and chromaticness). When we want to specify only the chromaticness of a stimulus, without regard to its brightness, we usually normalize the tristimulus values in the following way:

$$x = X/(X+Y+Z)$$
$$y = Y/(X+Y+Z).$$

The quantities x and y are known as chromaticity co-ordinates and can be plotted in the well-known CIE chromaticity diagram, figure 4. The horse-shoe shaped limit to this diagram is the locus of monochromatic (single-wavelength) stimuli. All other stimuli fall within this limit.

The CIE system is a specification of the amounts of three primary stimuli needed to match the stimulus being specified. It is not a specification of appearance. The amounts are determined by the amounts of radiation absorbed by each of the three types of cone photo-receptor in an average human eye.

Munsell System

It is possible to describe the appearance of a colour stimulus in words based on our perception of it. The trichromatic theory of colour leads us to expect that this perception will have three dimensions or attributes and our everyday experience confirms this. One set of terms for these three attributes is "hue", "brightness", and "saturation." Hue is the attribute according to which an area appears to be similar to one, or to proportions of two, of the perceived colors red, orange, yellow, green, blue and purple. Brightness is the attribute according to which an area appears to be emitting, transmitting or reflecting more or less light. Saturation is the attribute according to which an area appears to exhibit a greater or smaller proportion of chromatic colour.

For reflecting objects, "lightness" is often used instead of brightness. Lightness is brightness judged in proportion to the brightness of a similarly illuminated area that appears white.

The perceptual colour space formed by these attributes may be represented by a three-dimensional geometrical model. One such model is the Munsell System, illustrated in figure 5. In the Munsell System, the term "value" is used instead of lightness, and the term "chroma" is similar to "saturation". The achromatic colours (black, grey, white) are represented by points on a vertical axis. Horizontal planes contain colours of constant value. Within these planes, the various hues are arranged in a circle with a gradual progression from red, through orange, yellow, green, blue, purple, and back to red. Chroma increases as we go from the centre of the circle outwards along a radius.

An advantage of the Munsell System is that collections of carefully standardized colour chips, illustrating the system in mat or glossy surface, may be obtained from the Munsell Colour Company.

Chromatic Adaptation

The perceived colour of an object depends not only on the stimulus reflected from the object itself, but also, on, other stimuli in the field of view, the perceived colour of the illuminant, and on previously viewed stimuli.

Colour Differences

Distances in the CIE (x,y) chromaticity diagram or in CIE (x,y,z) tristimulus space do not correlate well with the perceived magnitude of colour differences. For this reason various transformations (called colour-difference formulae) have been suggested that provide more uniform spacing. Although none of the transformations are perfect, several of them do provide reasonably good approximations to the ideal and are useful in specifying colour tolerances. The most common are two formula recommended by the CIE and known as CIELAB and CIELUV.

Correlated Colour Temperature

Correlated colour temperature is a common, but a potentially misleading, term. It originates from the fact that, many years ago, the only sources of light were heated bodies (candles, fires, incandescent lamps etc.). The colour of a heated body depends to some extent on its spectral reflectance, but to a much larger extent on its temperature. The locus of chromaticities of heated black bodies can be calculated as is shown in figure 4. For an observer adapted to daylight, the colour varies from red and low temperatures (1000 kelvins) through orange, yellow and white to blue at very high temperatures (10 000 kelvins).

Using this locus as a reference, the correlated colour temperature of a light source is defined as the temperature of the closest point on the locus. (Closest being interpreted in the sense of smallest colour difference). Unfortunately, correlated colour temperature is not a complete colour specification. It says nothing about how far a source is from the black-body locus (i.e. how green or purple it is).

Colour-Rendering Index

Knowledge of the colour (chromaticity) of a light source does not enable us to predict the colour (chromaticity) of an object illuminated by the light source. To do this we need to know the spectral power distribution of the source and the spectral reflectance factor distribution of the object. Only this information allows us to calculate the spectral power distribution of the stimulus reflected from the object, and hence to calculate its chromaticity. Two metameric light sources, such as those shown in figure 3, will render the colours of objects differently even though the sources themselves are the same colour.

The CIE has recommended a method for assessing the colour-rendering properties of light sources. It rates lamps in terms of a colour-rendering index that is a measure of the degree to which the perceived colours of objects illuminated by a source conform to those of the same objects illuminated by a reference source.

The method consists of calculating the chromaticity shifts of eight test objects, correcting for chromatic adaptation, calculating the average colour difference, and subtracting from 100. Thus, the maximum value of the colour-rendering index is 100, but the minimum is undefined. Negative colour-rendering indices can and do occur.

One limitation of the colour-rendering index is that the reference source must always be chosen to be of similar colour to the test source. This is because colour scientists have not yet developed an accurate method to calculate the effect of chromatic adaptation when the difference between the two sources is large. Consequently, colour-rendering indices of lamps of different colour are not directly comparable. For example, both an incandescent lamp and natural daylight have a colour-rendering index of 100, but their colour-rendering properties are quite different.

The correlated colour temperatures and colour-rendering indices of some common types of lamps are listed in Table 1.

Colour-Preference Index

A colour-preference index is sometimes used as a measure of the degree to which the perceived colours of objects illuminated by a source conform to the preferred colours of the same objects. It is calculated in the same way as the colour-rendering index except that the true colours of the objects under the reference source are replaced by their preferred colours (usually more saturated).

This index has not been given any official recognition by organisations such as the CIE or the IESNA (Illuminating Engineering Society of North America).

Hospital Lighting

The importance of colour in hospital lighting may be discussed conveniently in four categories:

(i) Diagnosis. Skin colour is often a factor used by a doctor or nurse in his/her diagnosis of a patient's condition. Accurate colour-rendering (i.e. high colour-rendering index) and conditions that aid colour discrimination are obviously important. The illumination level should be reasonably high and the surrounding areas (bedsheets, walls etc.) should not contain highly saturated colours that might distort the appearance of the patients skin.

(ii) Surgery. Both colour rendering and colour discrimination are again important; but perhaps colour discrimination is paramount. The surgeon and his assistants (such as the anaesthetist) must be able quickly and accurately to detect slight changes of colour of the skin and other parts of the body.

(iii) Psychology. A patient's perception of his/her own health is an important factor in recovery from illness or surgery. Illumination that causes a patient to look healthy rather than pale and sickly can be of benefit here.

(iv) Coding. Many items in a hospital, such as drug labels, gas cylinders and pipes, fire-fighting equipment etc., are coded by colour. The background around these colours should be kept as free as possible from competing colours and the colours should be illuminated by a source which permits positive identification of the colour and the message which it is intended to convey.

Conclusions

1. The two most common systems of colour specification are the CIE System and the Munsell System. The CIE System is related to measurable quantities and predicts when two physically different stimuli will look the same. The Munsell System is based on a series of real colour samples and can be used to specify appearance in defined conditions.

2. Light sources are specified by their spectral power distribution. Some of their properties can be summarized by single-number indices such as correlated colour temperature and colour-rendering index, but these abbreviated specifications should be used with caution.

3. Colour is important in many ways in a hospital. Accurate colour rendering, precise colour discrimination, and colour preference are all factors in different applications.

Table 1

Common Lamp Types

	Correlated Colour Temperature (T_c)	Colour Rendering Index (R_a)
Natural daylight	6500	100
Incandescent	2850	100
Warm White	3020	52
Warm White Deluxe	2940	73
Cool White	4250	62
Cool White Deluxe	4050	89
Three-band (CW)	4200	82
Simulated D_{65}	6520	91
Clear mercury	5710	15
Colour-improved mercury	4430	32
Metal Halide	3720	60
Low-pressure sodium	1740	-44
High-pressure sodium	2100	21

From IES Handbook, 1981 (Ref. 5)

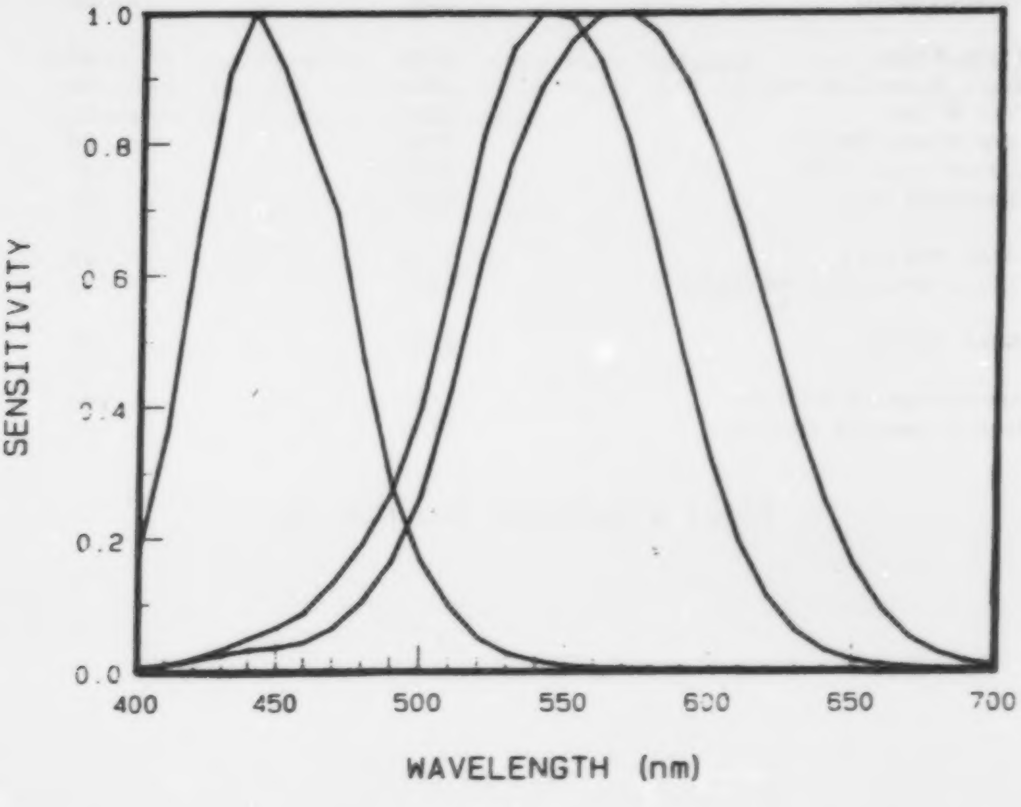

Fig. 1. ESTIMATE OF THE SPECTRAL SENSITIVITIES OF THE THREE TYPES OF CONE IN THE HUMAN EYE

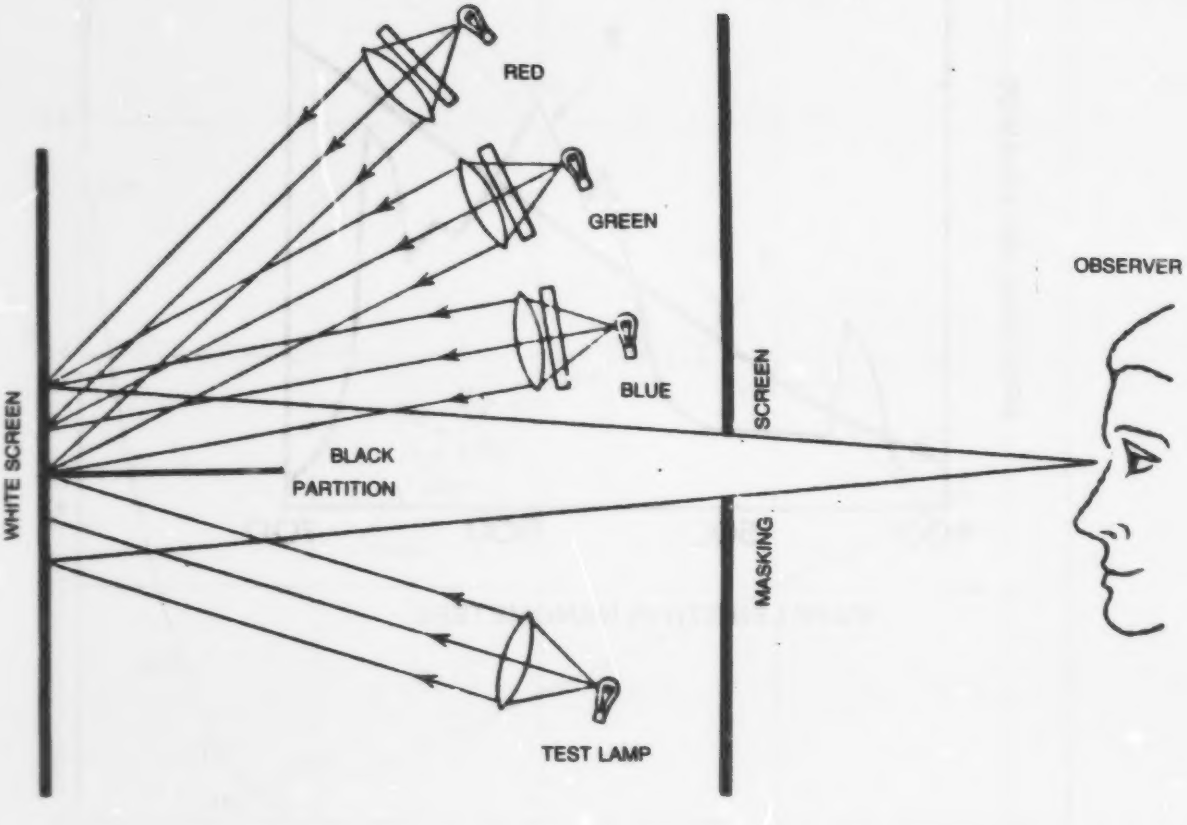
RED
GREEN
BLUE
OBSERVER
WHITE SCREEN
BLACK
PARTITION
MASKING
SCREEN
TEST LAMP

Fig. 2. ADDITIVE MIXTURE OF THREE PRIMARY STIMULI TO MATCH A TEST STIMULUS (FROM REF. 1).

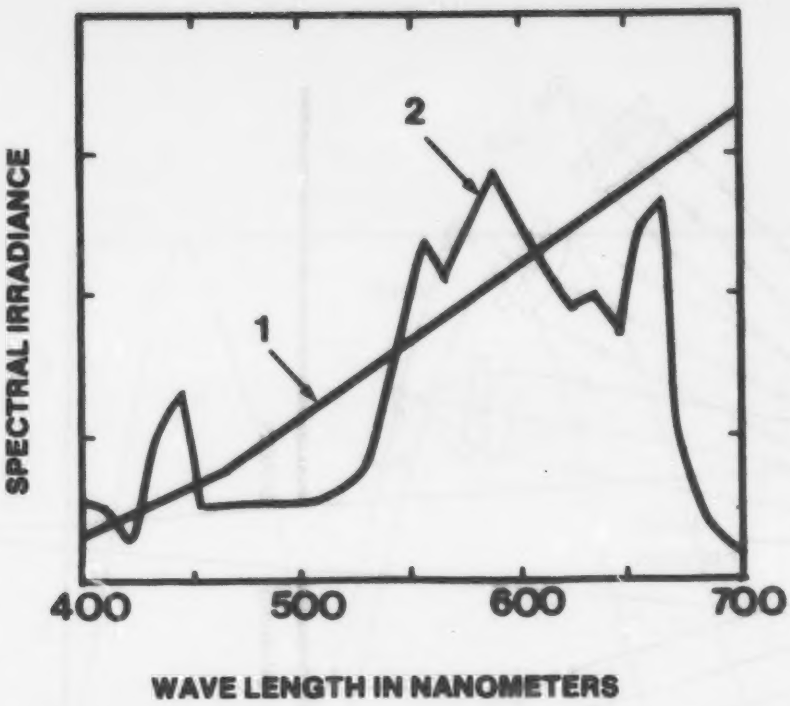

Fig. 3. SPECTRAL POWER DISTRIBUTIONS OF A PAIR OF METAMERIC LIGHTS (FROM REF. 5).

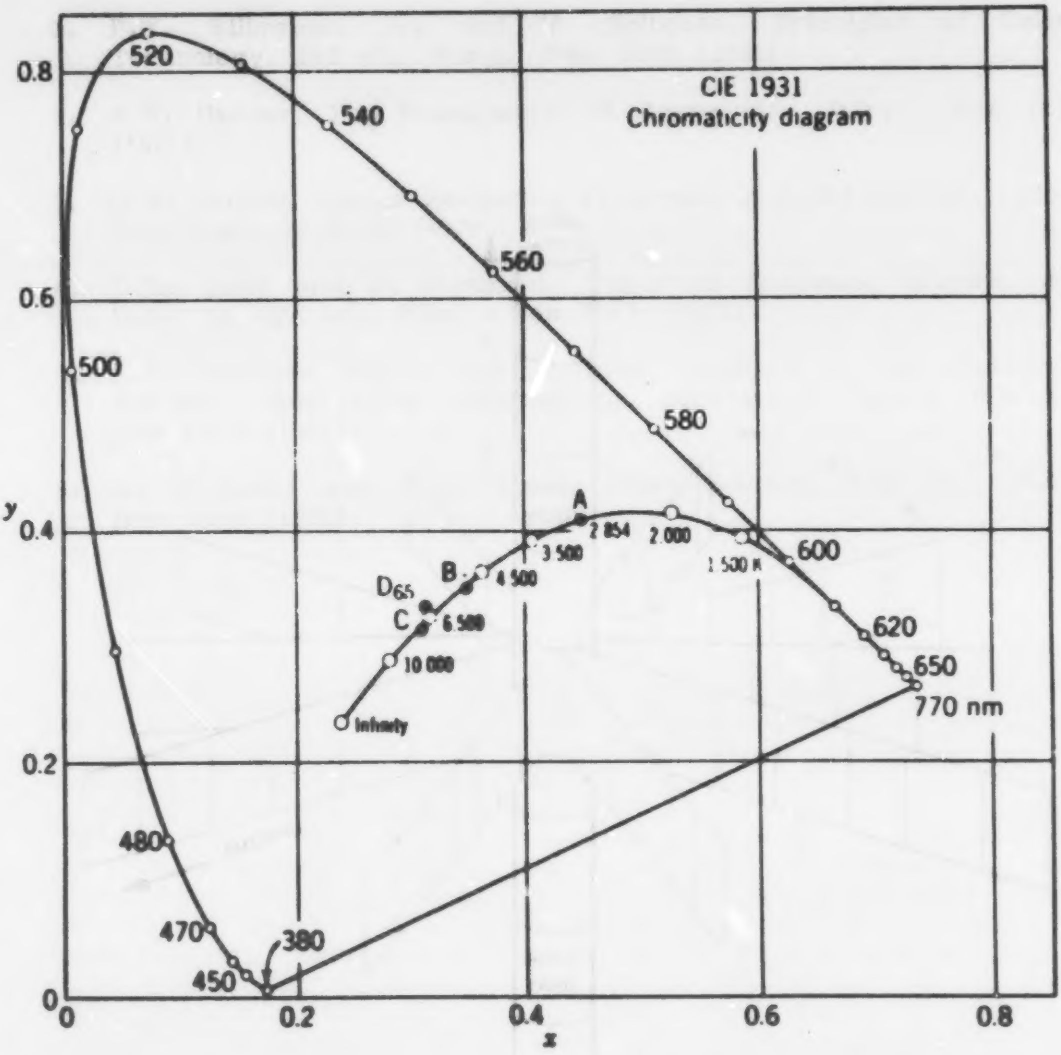

Fig. 4. CIE 1931 CHROMATICITY DIAGRAM WITH THE LOCUS OF BLACK-BODY CHROMATICITIES

The points marked A, B, C, and D_{65} are the chromaticities of CIE Standard Illuminants. (From ref. 4).

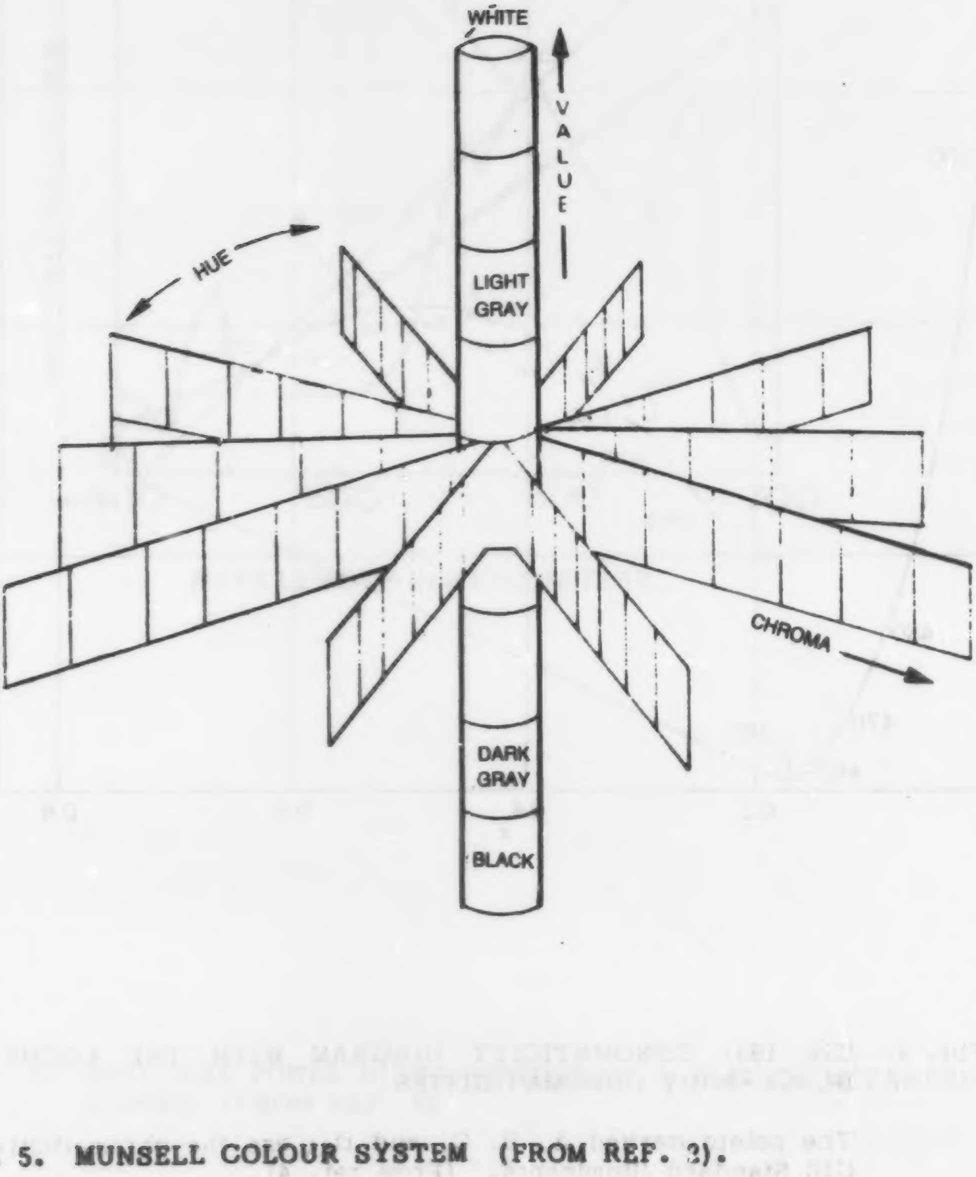
WHITE
VALUE
HUE
LIGHT GRAY
CHROMA
DARK GRAY
BLACK

Fig. 5. MUNSELL COLOUR SYSTEM (FROM REF. 2).

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THE IMPACT OF LIGHTING ON HEALTH

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If exercise of your selection of sources for lighting design must be tempered by concern of possible health effects, generated by the spectral composition of illuminants, you are going to be very limited in your choices. Much of what you have heard today and are about to hear afterwards will be more or less useless if the illuminants you wish to use are proscribed because of alleged health effects.

It is my intention to present to you today information that I trust will alleviate any anxiety you may entertain associated with possible health effects due to the spectral composition of illuminants. First, we must inquire why we might suspect that the spectral composition of illuminants used for general lighting can induce physiological effects. It has been claimed that since man has evolved under a particular illuminant one might expect that he is therefore adapted to it. This is certainly reasonable. But just what is that so-called "natural" illuminant to which man owes his evolution?

The pervading assumption has been that the "natural" illuminant is sunlight in an open sky. Thus, any spectral power distribution which is different than sunlight is to be suspected of producing harmful biological effects due either to the lack of particular wavelengths or to a wavelength composition different than that found in sunlight. However, the evidence of paleobiology, physical anthropology, physiology, anatomy, and of the visual sciences indicate that the primates, of which Homo sapiens represents the latest development, evolved for some 80 million years not in the light of the sun in the open sky but rather in the light of the forest. The light under a forest canopy differs markedly from sunlight in the open sky. Forest light, as a result of the spectral absorption and reflection characteristics of foliage has a spectral power distribution which peaks in the "yellow-green", at the same wavelength that the eye sensitivity of man peaks, as seen in figure 1. The correspondence of eye sensitivity and the spectral composition of forest light is hardly an evolutionary coincidence. There is a large body of convincing data showing that the eye sensitivity of organisms matches closely the spectral characteristics of the environment in which they have evolved.

There are other factors which confirm that man is adapted to forest light. Of most significance is the retinal organization. The retinae of animals which inhabit open country are quite different from those that inhabit the forest. Open country animals have need for visual information which is confined to a more or less narrow horizontal area on the retina. In these animals, the retina is so organized that his horizontal strip, the so-called "visual streak", is an area of high visual acuity. In contrast, animals of the forest require visual information vertically as well as horizontally, and thus evolution has produced retinae of forest creatures which contain a circular area of high visual acuity. The retina of Homo sapiens falls in the latter category; his eye displays the same type of retinal organization as do the forest inhabitants.

In addition, one has only to consider how hostile sunlight is to the human to question open sunlight evolution. Skin cancer, sunburn, cataracts, and retinal degradation are some of its "benefits" to man. We cannot even visually adapt to the intensity of sunlight in the open sky. We squint or use sunglasses. After exposure to bright sunlight, our visual sensitivity is drastically reduced. The sensitivity loss can last for as long as 48 hours. The open country animals do not suffer such disability.

The only positive benefit that has been demonstrated for sunlight is the synthesis of vitamin-D. Yet the amount of ultra-violet necessary is quite small and can be obtained from the forest light. Forest primates do not experience vitamin-D deficiency.

The thesis that human health requires exposure to the spectral composition of sunlight because of an evolutionary heritage does not stand scrutiny. Only the light under the forest canopy might satisfy the assertion that evolution demands a particular illuminant. It is ironic that the cool white fluorescent lamp which has a spectral composition quite similar to that of forest light is so often accused of "unnaturalness" see figure 2.

There is another difficulty, usually ignored by those who would have you use a particular illuminant. It is generally not recognized that the attempt to provide an environment with a particular spectral composition is consistently frustrated because the spectral power distribution of the lighted space is effectively controlled by the spectral reflectivity of the coloured surfaces that envelop that space. These surfaces "distort" the wavelength composition of the illuminant. It is precisely that "distortion" which produce the colours of the surfaces. It is the light that reflects from the walls, carpets, and furnishings which determine in large part the spectral composition of the light that enters our eyes and impinges on our skin. Thus the only way to experience the unchanged spectral composition of the illuminant is to inhabit a colourless environment, one in which the walls, floors, ceilings, and furnishings, including clothing worn by the inhabitants, consists of only white and/or various shades of grey.

But this is really a false issue. There are no photochemical or visual mechanisms which require unique spectral compositions, since wavelength "information" is lost in the very first step of any photochemical process. When light is absorbed by the pigment molecules in the retina, for example, these molecules are raised to an excited photochemical state. The probability that a photon of a particular wavelength is absorbed is a function of wavelength. The spectral sensitivity is a description of that probability and that description indicates that a broad band of wavelengths can be absorbed by the pigment. But the pertinent point is that the excited state is the same regardless of the wavelength of the light that produced it. There is nothing in the visual system that can distinguish between, for example, a spectral "yellow" light of 580 nanometers and a matching light consisting of a combination of a "red" light of 610 nanometers plus a "green" one of 540 nanometers. There is no difference between the neural information leaving the eye resulting from these two "yellow" lights. Similarly, there is no difference between the neural stimuli resulting from viewing an illuminant that mimics the spectral composition of sunlight and one which consists of a radically different spectral composition but which matches sunlight in appearance. This is the neurophysiological meaning of metamerism. So if light has any physiological effects, any of many spectral power distributions will suffice, not just the "natural" one.

If wavelength is not involved, then how does one explain the sporadic research reports that present an opposite conclusion? Some of these have claimed that the wavelength composition of illuminants have had significant effects on the physiology and growth of animals. These data have been disputed because dubious experimental protocols were employed. It is important to note that only nocturnal animals were used in the experiments. Such creatures have evolved biological strategies in the absence of sunlight. These animals are not physiologically adapted to sunlight. They are often blinded when subjected to even the brightness levels of the ordinary bilogical laboratory. Sunlight is a most unnatural illuminant for these creatures. Yet we are asked to extrapolate biological responses from these nocturnal creatures to the human and to infer that illuminants that differ from sunlight are somehow deleterious to the diurnal animal, Homo sapiens! This is most curious since the rationale for the experiments in the first place was the importance of evolutionary pressures on physiological adaptation. How does one evaluate the evolutionary importance of sunlight to a creature that evolved in its absence?

For example, in one experiment with a nocturnal animal it was found that the adrenals were heavier under a sunlight-simulating spectral power distribution. The implication that was drawn was that since the adrenals were heavier under the sunlight-simulating spectral power distribution, that illuminant was healthier than the test illuminant. In a second experiment testing the sunlight simulating illuminant against a different lamp, it was found that, conversely, the adrenals were lighter under the sunlight-simulating lamp. Again the implication was drawn that the sunlight simulating lamp was healthier. On what basis the heavier and lighter adrenals were deemed healthier was not stated.

What is more disturbing is that while both experiments were run by the same investigator he did not draw the reader's attention to the contradiction.

The difficulty is that the differences that are observed are quite small and they have to be teased out of the data by statistical techniques. In these experiments the results are never clear; they always require statistical techniques. Usually many factors are examined with perhaps one showing a statistical significance. If one examines twenty factors it is expected that one factor will show a statistical significance at the 5% confidence level even if there is no significance to the result. I am not aware of any published paper which reports an investigation in which the data was tested for reproducibility. I do know, however, of one study in which reproducibility could not be shown. It is difficult to rigorously eliminate extraneous factors in such experiments.

The most egregious fault, however, is the use of erroneous spectral sensitivity factors for the nocturnal animal. The eyes of nocturnal animals have a different spectral sensitivity than that of the human. This means that a photopic footcandle meter is not an acceptable instrument to equate brightnesses for a laboratory rat. The illuminances will be equated for the experimenter not for the experimental animal. Since nocturnal animals respond to brightness differences with different levels of stress, for instance, one must eliminate any brightness difference from an experiment which is attempting to determine the effect of wavelength composition. This is just what has not ordinarily been done and therefore all such experiments have been contaminated with an extraneous factor, unequal brightnesses. Whatever the results may indicate spectral composition cannot be implicated unambiguously since unequal brightnesses also existed, representing a significant experimental contaminant.

I have only been able to present a fraction of the pertinent material relating to this subject matter. I hope, however, that the material presented will allow you not to feel constrained in your choice of sources because of unfounded claims of health risks attributed to particular illuminants.

To Sum:

1. The assertion that illuminant spectral power distribution can effect health has yet to be shown. The experiments with nocturnal animals have been few, contradictory, and flawed, particularly because brightnesses of sources were improperly controlled.

2. The assertion is inconsistent with our present understanding of the mechanisms of photochemistry and vision. There is no known mechanism by which wavelength "information" can survive in the neural path leading from the eye, nor can it survive the excitation

of any photoactive molecule. Metamerism serves the biological function as it does the visual. Therefore any light source which is visually effective will be biologically effective.

3. The primary assertion that sunlight is the "natural" illuminant does not stand scrutiny. Humans and their primate ancestors evolved in the light of the forest. This light is greatly different from sunlight in the open sky.

4. And finally, let me add, there are no robust clinical data indicating that spectral power distribution of illuminants used for interior lighting constitutes a health problem. That there might be such effects is purely conjectural and based on a proposition which does not stand examination.

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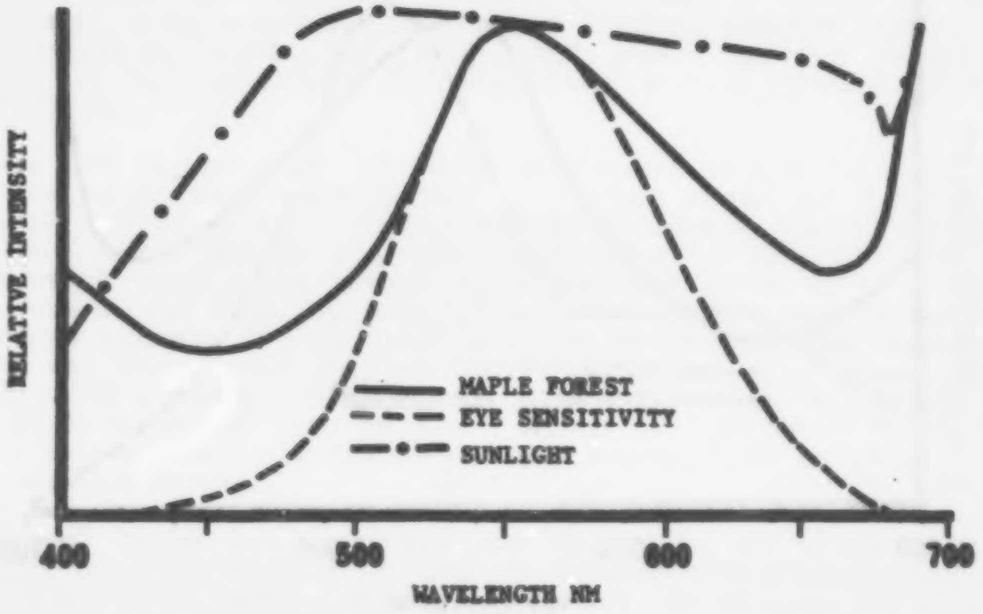

Fig. 1 Comparison of the human spectral sensitivity to that of forest light and sunlight.

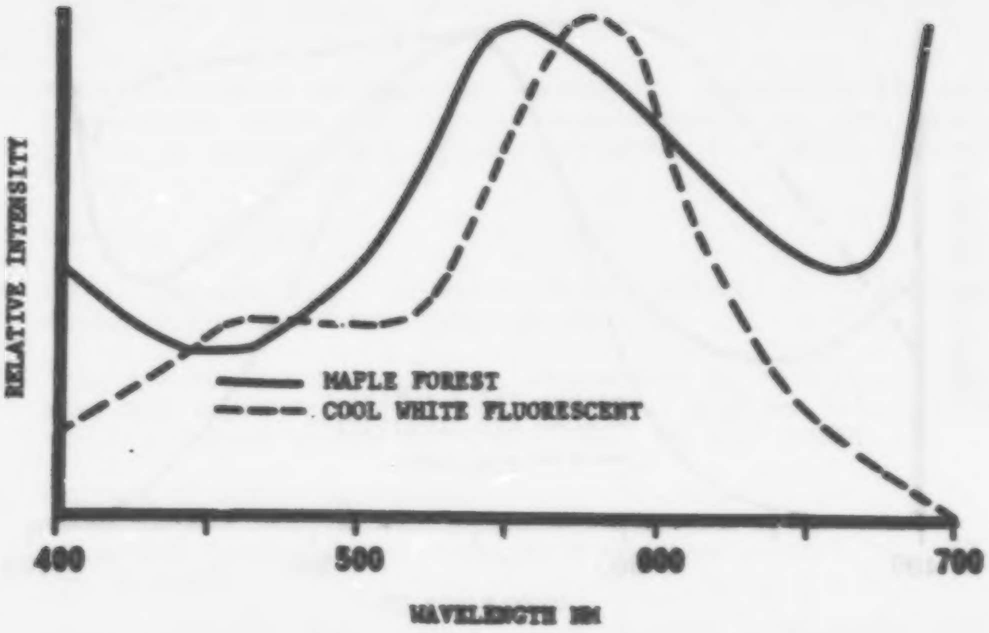

Fig. 2 Spectral composition of light in a maple forest and that of a cool white fluorescent lamp.

A SYSTEMS APPROACH TO THE APPLICATION OF FLUORESCENT LAMPS FOR GENERAL LIGHTING SYSTEMS

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Introduction

In order to reduce the energy used by fluorescent general lighting systems, cut costs, and to make such systems operate more efficiently, lighting equipment manufacturers have introduced a variety of new products. Some are simple redesigns of standard products which use less energy and provide lower light output; others represent the application of new technology to substantially improve lighting system performance.

There are an estimated 100 million fluorescent sockets in place in Canada so any short range significant reduction in the use of lighting energy depends upon modifications that can be made to existing systems without major retrofit and conversion costs. Reduced wattage fluorescent lamps using krypton filled gas were developed as a first response to this need, but because fluorescent ballasts tend to operate lamps at constant current, there is a limit to what the lamp manufacturer can do to reduce lamp wattage without compromising system reliability. In practice light output and wattage reductions have amounted to 18-20% for instant start (slimline) circuits but only 10-14% for rapid start circuits which, unfortunately in this context, make up almost ¾ of the installed sockets.

The next logical step, therefore, was to include the ballast in the energy reduction effort in an effort to squeeze more efficiency out of the total system, keeping in mind while users may be willing to accept reduced lighting levels in hallways and other non-work areas, they are reluctant to accept substantial reductions in areas where visual tasks are performed and where lighting is needed to get the work done.

Low Loss Ballast

The first approach to improving ballast design involved the use of different materials in existing ballast design. No major electrical changes were made in open circuit voltages or operating current wave forms. The material changes included an improved transformer winding process utilizing "flat" copper wire technology along with the use of high grade steel to improve magnetics and reduce transformer losses. These changes alone resulted in ballast losses being substantially reduced by up to 50%, from 16 watts to 8 watts on a 2 lamp F40 rapid start design, while providing full light output with standard F40 lamp designs. The reduced ballast losses also provide the added feature of lowering ballast case temperature, thus, substantially extending ballast life 2-3 times (25 to 30 years).

Low loss ballasts are compatible with reduced wattage lamps, however, system performance will vary.

High Performance Ballast

The second approach to improving ballast design was to develop a low loss high performance ballast specifically for existing reduced wattage lamp designs to improve overall system efficiency.

Fluorescent lamp lumen output, as defined in various manufacturers literature, are derived from photometric measurements while operated on a "reference" ballast, as seen in figure 1. This "reference" ballast is a laboratory device that meets certain ANSI specifications and provides the industry with a uniform measurement system.

The typical commercial ballast, however, does not provide full lamp lumen output in actual installations and this performance differential is expressed in the lighting calculations procedure as Ballast Factor (BF)

$$BF = \frac{\text{Lamp lumen output on commercial ballast}}{\text{Lamp lumen output on reference ballast}}$$

Ballast factors for standard F40 lamps are typically .95 on CBM certified ballasts, while reduced wattage lamps due to their different electrical characteristics typically have a ballast factor of .89 on the same commercial ballast.

This shift in ballast factor for the reduced wattage lamp led to the development of a wave form modified low loss ballast designed to maximize reduced wattage lamp performance. Like the low loss ballast the high performance ballast utilizes both the flat wire winding process and high grade steel core with the addition of a modified wave form circuitry and a higher capacitor value to improve reduced wattage lamp performance.

A comparison of lamp performance is shown in Figure 2.

The improved ballast factor (.97) for the standard lamp when used with the low loss wave form modified ballast prompted the development of a high lumen Lite White 40 watt lamp that when combined with the high performance ballast provides a system lumen performance advantage of up to 27% when compared to the standard F40 system.

Hybrid Optimised System

The third approach to lamp and ballast systems has been the development of a hybrid low loss electromagnetic ballast incorporating a solid state voltage sensitive "Sidac" switch to control the filament transformer. A newly designed 28 watt lamp with a special cathode structure allows the lamp to operate properly without cathode heat. When the system is first energised voltage is impressed across the solid state switch allowing normal cathode heating. Once the lamp has started lamp voltage drops causing the switch to turn off the filament transformer thus further reducing ballast and lamp losses.

Typically the hybrid system provides a wattage reduction of up to 40% compared to the standard system, with a minimal reduction in system light output of 9%.

Figures 4 and 5 illustrate a typical system light output and wattage comparisons for equal maintained footcandle or equal number of luminaires.

Fluorescent System Considerations

The development of the systems concept requires that lighting designers and specifiers become more aware of light loss factors that rob the lighting system of lumens. One such factor (BF) was discussed previously, another is TF or Temperature Factor.

The fluorescent lamp is the only major light source which is sensitive to ambient temperatures. If watts are removed from the luminaire by using reduced wattage lamps or low loss ballasts, less heat will be generated and the operating temperature point of the lamps will likely change.

The general relationship between fluorescent lamp performance and temperature is shown in Figure 6. The critical area as far as the fluorescent lamp is concerned is the coldest spot on the bulb surface. This spot controls mercury vapor pressure inside the lamp increasing or decreasing the amount of ultraviolet energy available to activate the phosphor. Most fluorescent lamps are designed to peak in light output around 100^{O}F cold spot temperature. Above this value too much mercury vapor is present in the lamp and ultraviolet energy is absorbed with a subsequent reduction in both light output and power input. This is a common mode of operating in many installations, particularly where the lamp is enclosed in multi-lamp luminaires mounted against low density ceiling materials. It is not uncommon to find lamps under such conditions which operate from 10 to 25% below rated output. Temperature data do not normally appear in a luminaire manufacturers' specification sheet since they are automatically included in the coefficient of utilization (CU) information calculated from the photometric test of the luminaire. An indication of this can be seen from an examination of CU tables which frequently show that CU's are lower for 4-lamp equipment than for similar 2-lamp. Most of the differences is due to higher lamp temperatures in 4-lamp units.

As lamp temperature falls below optimum, mercury is condensed out at the cold spot and light output drops dramatically as the arc becomes "starved" for mercury vapor. Lamp watts remain relatively high since power is being used to heat the lamp, so there is a substantial reduction in lamp efficacy (lumens per watt) on the cold side of the curve. The results are very apparent where temperatures fall 40 to 60 degrees below optimum. In addition, the reduced wattage lamp designs may also show signs of instability--flickering, flashing or "racoon trailing" (a phenomenon that looks as if there are dark concentric bands moving back and forth along the length of the lamp) at ambient temperatures below 60°F.

While cold temperature operating has not been particularly common in interior lighting systems, it may be encountered more frequently now because:

1. During the winter, lower night and weekend temperature setbacks in buildings will result in lower room temperatures when lamps are first turned on.

2. As lighting system watts per fixture are reduced, in any number of ways, less heat is available to warm the lamp.

Even during summer operation, lamps may be found on the cold side of the curve. Bare lamps in the path of low temperature air from air diffusers is one common occurrence.

Luminaires, which are equipped to exhaust room air into a duct or plenum by passing the air over lamp surfaces, generally operate the lamp close to its optimum temperature point. Other advantages with this mode of operating are cleaner fixtures, because of increased air circulation, and longer ballast life, due to reduced ballast temperatures. While operating a fluorescent lamp either under or over optimum temperature within the range, shown in Figure 6, may affect output and efficiency, it has little effect on lamp life. The important point is that since both luminaire light output and ballast input wattage are affected by the thermal operating point of the lamps, a given lighting system with various lamp/ballast combinations can vary widely from its published performance which is normally based upon "bench" or reference data.

To obtain some idea of this variability different luminaire types equipped with nominal 40 watt lamps and two lamp ballasts and were thermally, electrically and photometrically monitored. Figures 7 and 8 show the results in graph form for 5 different lamp/ballast combinations.

The curves confirm that the thermal effects can be substantial. For a given ballast and lamp, system watts can actually be more than 15% below nameplate ratings and light output can be 25% less than the manufacturers published values.

A preliminary idea of the "best" lamp/ballast combination may be obtained by examination of the curves. Figures 4 and 5 summarize the various system data for a typical four lamp recessed troffer system. For example, if a new installation is being considered, the most light output per luminaire for a given illumination level (and the fewest number of luminaires) would result from using the high lumen 40 watt lamps with a high performance low loss ballast. For a system where luminaire spacing is fixed, consideration might be given to either the 3 lamp high lumen system or hybrid 4 lamp system for lowest watts per square foot.

Economics

Table 1 provides a typical detailed economic analysis of the various systems discussed. Prices shown for luminaires and lamps are typical estimated trade nets. Note that particular attention has been paid to the values of input watts per luminaire, ballast factor, and coefficient of utilization. (lines 5, 6, 7). In this analysis values were determined experimentally and entered as separate items assuming the optical efficiency and, therefore, the coefficient of utilization of the luminaires remains constant for each fixture type for all of the combinations of lamps and ballasts. This is correct since optical efficiency will not change unless lamp diameter or length changes.

In the cost analysis tables the temperature effects are included in the ballast factor information; although a better way might be to bring them out separately as a "temperature factor" so that the initial light output of the luminaire is:

$$L_{LUM} = L_{LMP} \times TF \times BF \times OE$$

where L_{LMP} = Initial Rated Lamp Lumens

TF = Temperature Factor

BF = Ballast Factor

OE = Luminaire Optical Efficiency

and where for any given room geometry and set of room surface reflectances OE is directly proportional to the coefficient of utilization.

Also note that for enclosed luminaire types which ordinarily operate the lamps at higher temperatures (4 lamp recessed troffer) replacing standard lamps with high efficiency reduced wattage lamps may result in a net increase in luminaire output even though the reduced wattage lamps are rated for less output than standard lamps.

Summary

The proliferation of new lamps and ballasts for fluorescent lighting systems has broadened the choices available to the lighting user and specifier. Some cost and energy savings are possible simply by replacing lamps or ballasts in existing systems with little or no reduction in system light output. Combining the best features of reduced wattage high efficiency lamps or high lumen standard lamps and low loss high performance ballasts into a system maximizes the potential savings and makes possible new lighting systems using fewer fixtures with no reduction, and perhaps even an increase, in average illumination for some types of luminaires.

Careful analysis is required to evaluate these new combinations of lamps, ballasts and luminaires.

LIGHTING COST WORK SHEET

DATE
CUSTOMER
INSTALLATION

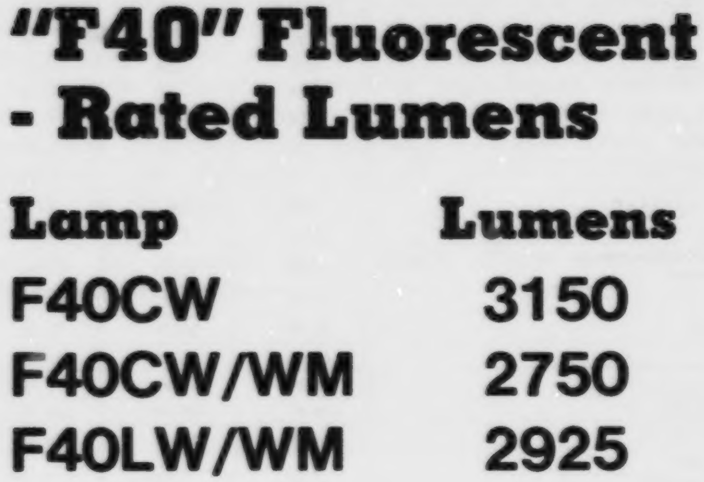
Fluorescent Systems
4 - Lamp Recessed Troffer

	LIGHTING SYSTEM DESCRIPTION	STANDARD LAMPS STANDARD BALLAST	HIGH EFF. REDUCED WATTAGE LAMP STANDARD BALLAST	HIGH EFF. REDUCED WATTAGE LAMP LOW LOSS BALLAST	HIGH EFF. LAMP HIGH EFF. BALLAST	28 WATT HY-BRID SYSTEM
		BASE	II	III	IV	V
BASIC DATA	1. Rated initial lamp lumens per luminaire	12600	11700	11700	13800	10200
	2. Rated lamp life (Hours) at 3 hours per start	20000	20000	20000	15000	15000
	3. Group replacement interval (Hours)	SPOT	SPOT	SPOT	SPOT	SPOT
	4. ~~Average~~ watts per lamp (nominal)	40	34	34	40	28
	5. Input watts per luminaire (including ballast losses)	176	156	137	169	116
	6. Coefficient of utilization	.75	.75	.75	.75	.75
	7. Ballast factor (Fluorescent) - Thermal Factor	.95	.96	.94	1.00	1.07
	8. Lamp depreciation factor - LLD	.876	.876	.876	.91	.895
	9. Dirt depreciation factor - LDD	.747	.747	.747	.781	.781
	10. Effective maintained lumens per luminaire (1 × 6 × 7 × 8 × 9)	5874	5512	5397	7355	5721
	10.A. Average footcandles on work surface (10 ÷ sq. ft. luminaire) 80 sq. ft.	73.4	68.9	67.4	91.9	71.5
	11. Relative number of luminaires needed for equal maintained footcandles (10 of base system ÷ 10 of system compared)	1.000	1.066	1.088	.799	1.027
INITIAL COST	12. Net cost of one luminaire	45.00	45.00	59.00	62.00	70.00
	13. Wiring and distribution system cost per luminaire	35.00	31.00	27.00	34.00	23.00
	14. Installation labor cost per luminaire	45.00	45.00	45.00	45.00	45.00
	15. Net initial lamp cost per luminaire	4.00	7.90	7.90	12.30	15.00
	16. Total initial cost per luminaire (12 + 13 + 14 + 15)	129.00	128.90	138.90	153.30	153.00
	17. Annual owning cost per luminaire (% of 12 + 13 + 14)	18.75	18.15	19.65	21.15	20.70
	18. Relative initial cost for equal maintained footcandles (16 × 11 of system compared ÷ 16 of base system)	1.00	1.058	1.164	.943	1.21
OPERATING COST	19. Burning hours per year	3500	3500	3500	3500	3500
	20. Number of lamps group replaced per year (19 × lamps/unit ÷ 3)	-	-	-	-	-
	21. Number of interim spot replacements (20 × Burn outs in GR interval)	-	-	-	-	-
	21.A. Number of lamps spot replaced per year - No group relamping (19 × lamps/unit ÷ 2)	.6	.6	.6	.8	.8
	22. Replacement lamp cost per year (20 or 21A × net lamp cost)	.72	1.18	1.18	2.46	3.00
	23. Labor cost for group replacements (20 × Group labor rate/lamp) at $ ____ / lamp	-	-	-	-	-
	24. Labor cost for spot replacements (21 × Spot labor rate/lamp at $ 5.00 / lamp	3.00	3.00	3.00	4.00	4.00
	25. Cost of cleaning per luminaire per year	-	-	-	-	-
	26. Annual energy cost per year (5 × 19 × ¢ KWH ÷ 100,000) at .06 ¢ KWH	36.96	32.76	28.77	35.49	24.36
	27. Total annual operating cost per luminaire (22 + 23 + 24 + 25 + 26)	40.68	36.94	32.96	41.95	31.36
	28. Relative annual operating cost for equal maintained footcandles (27 × 11 of system compared ÷ 27 of base system)	1.00	.96	.88	.82	.79
TOTAL	29. Total annual cost - owning and operating - per luminaire (17 + 27)	59.43	55.09	52.61	63.10	52.06
	30. Relative total annual cost for equal maintained footcandles (29 × 11 of system compared ÷ 29 of base system)	1.00	.988	.963	.848	[illegible]
	Number of Luminaires required for 70 [illegible]	119	126	129	95	[illegible]

CANADIAN GENERAL ELECTRIC COMPANY LIMITED - LAMP DEPARTMENT

LP - 980 10/70

Table 1.



"F40" Fluorescent - Rated Lumens

Lamp	Lumens
F40CW	3150
F40CW/WM	2750
F40LW/WM	2925

Fig. 1.

"F40" Fluorescent — Ballast Factors

Lamp	Lumens	Std. Ballast	Watt-Miser Ballast	Maxi-Miser II Ballast
F40CW	3150	.95	.935	.97
F40CW/WM	2750	.895	.875	.95
F40LW/WMII	2925	.895	.875	.95
F40LW/MMII	3450	.95	.935	.97

Fig. 2.

Fluorescent System Performance

For Equal Maintained Footcandles

	Relative # Luminaires (%)	Relative Watts/Sq.Ft. (%)
Std. System	100%	100%
Reduced Wattage Lamp/ Std. Ballast	110%	97.5%
Reduced Wattage Lamp/ Low Loss Ballast	112%	89.1%
High Performance System (4)	80%	76.8%
High Performance System (3)	99%	69.0%
Hybrid System	102%	67.2%

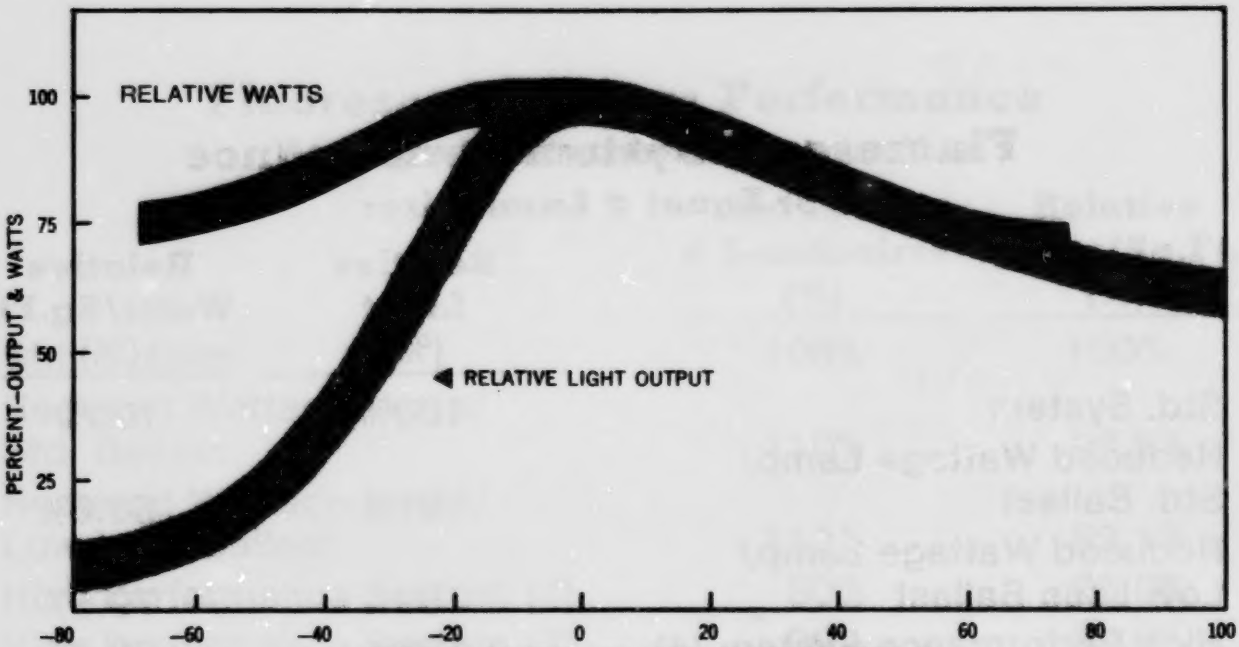
Fig. 4.

Fluorescent System Performance

For Equal # Luminaires

	Relative Light (%)	Relative Watts/Sq.Ft. (%)
Std. System	100%	100%
Reduced Wattage Lamp/ Std. Ballast	91%	88.6%
Reduced Wattage Lamp/ Low Loss Ballast	89%	79.5%
High Performance System (4)	126%	96.0%
High Performance System (3)	101%	70.0%
Hybrid System	98%	65.9%

Fig. 5.



Light output and wattage of fluorescent lamps vary as bulb wall temperature varies from the optimum of 100° F.

Fig. 6.

SYSTEM WATTAGE VS TEMPERATURE

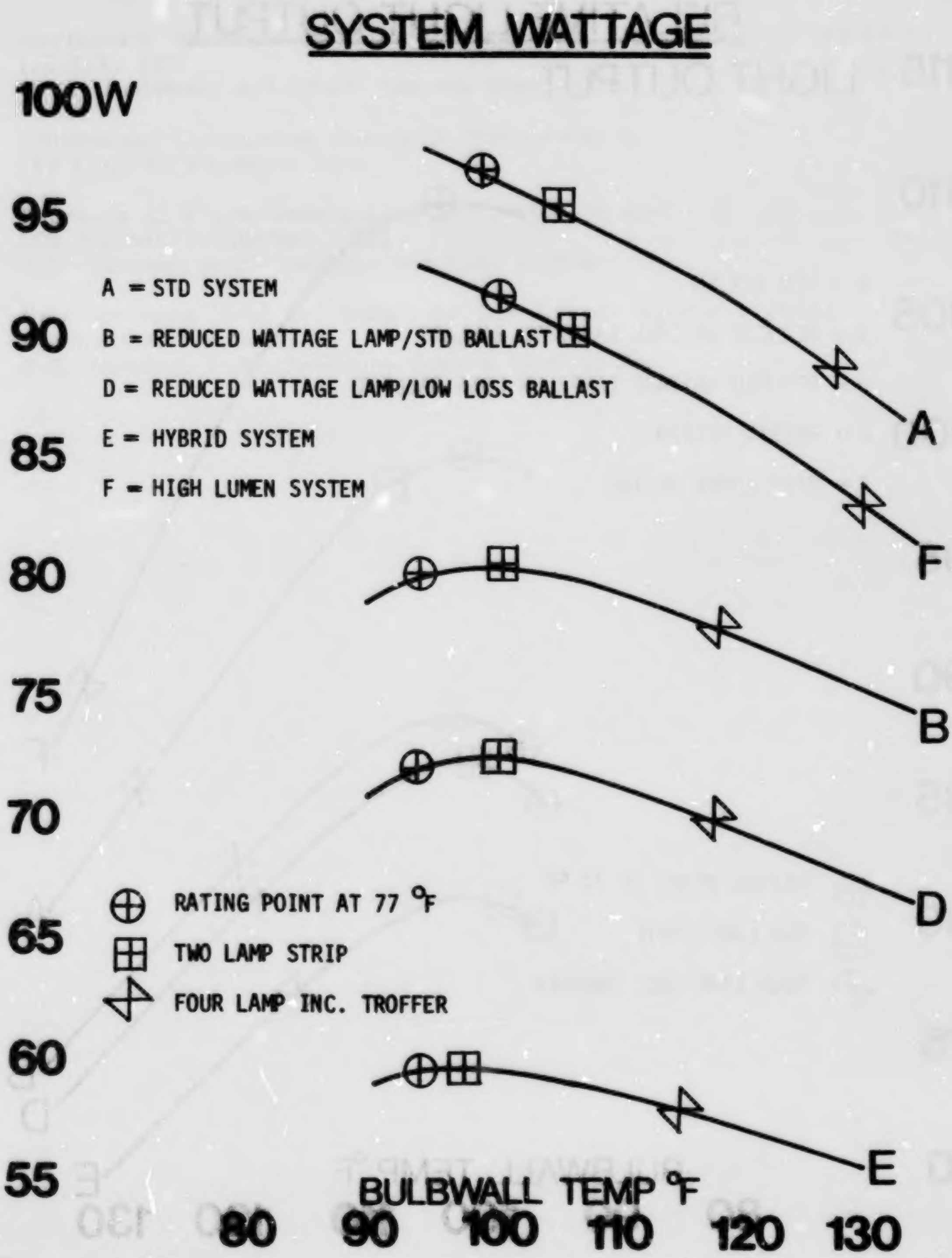


Fig. 7.

LUMINAIRE LIGHT OUTPUT VS TEMPERATURE

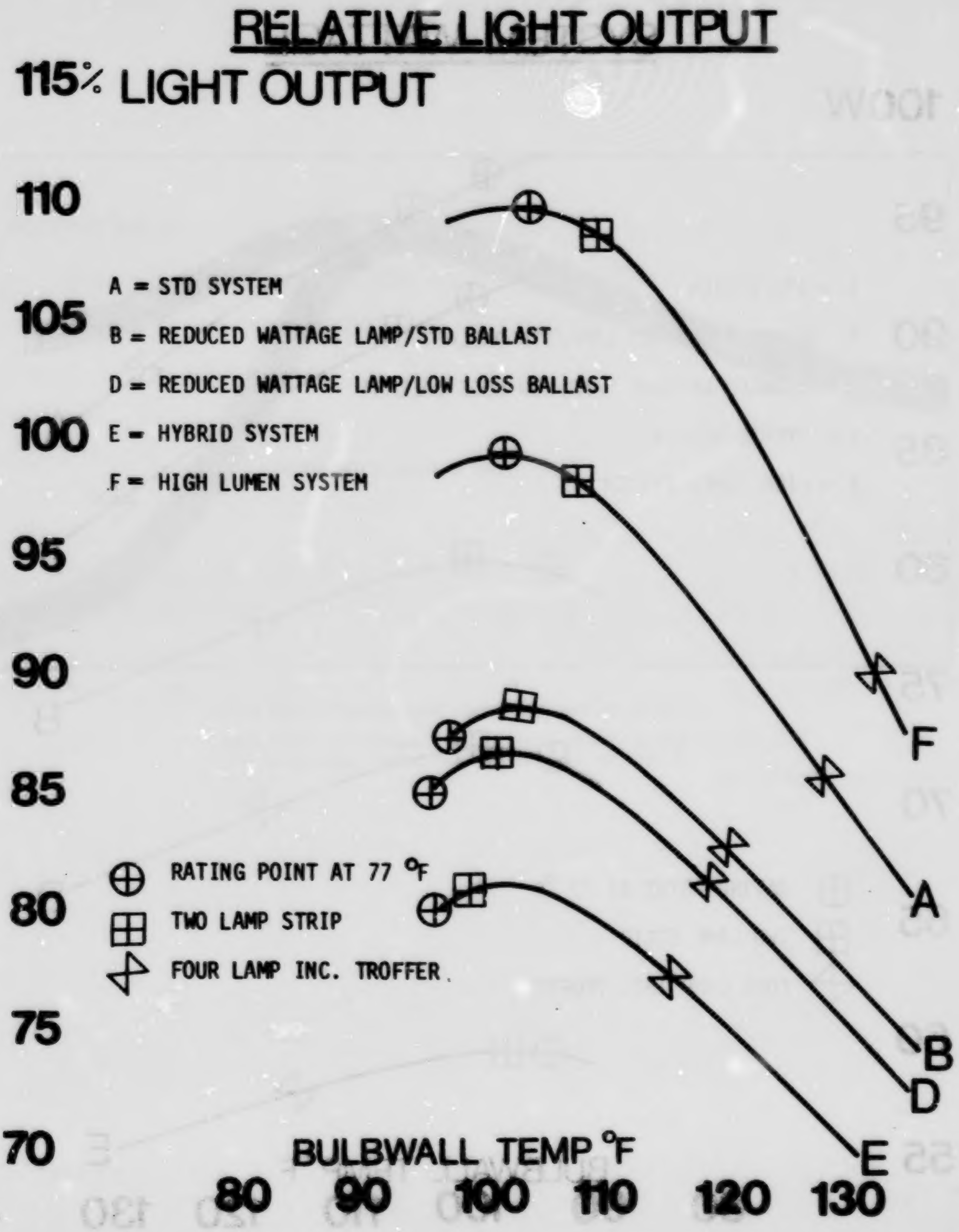


Fig. 8.

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130

DAYLIGHTING

DAYLIGHT AND WINDOWS IN HOSPITAL WARDS

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The function of windows in a patient's room or ward is complex. It involves the consideration of lighting, heating, air conditioning and acoustics. But, most important, it involves the well-being of the patient.

You will see from this short list of functions that windows and window design have two aspects - the qualitative and the quantitative.

The quantitative design - so that the windows provide a given amount of light and have a certain heat transfer - is straight-forward although inaccurate. The qualitative design is another matter. Both praise and criticism may be levelled at the same building. This, of course, is not unusual, but it is desirable to optimise the design so that the majority of occupants like the building. In this process one comes up against such considerations as ambience, orientation and contact with the outside - considerations which are very difficult to quantify.

The difficulty is exemplified by the conclusions drawn from two studies carried out not more than 200 miles apart in England. One study by Hardy in Newcastle concluded that there appears to be a case for office windows which are narrow and vertical rather than long and horizontal: the narrow and vertical windows avoid the "tracking" effect of the sun and also present the most interesting view. The other study by Keighley in Loughborough concluded that a horizontal window is preferred since it provides the best view. The confusion does not end here. I have recently completed a study into windows and I have been unable to corroborate either of these conclusions.

People generally prefer to be in a space with windows rather than one without windows. This preference implies that daylight creates an interior which is more pleasant and satisfying than one illuminated only by electric light. The main reason for this is that windows provide contact with the outside: they are the eyes of the hospital.

Some authors have concluded that this contact with the outside is the main aim of hospital windows: they do not consider that the main aim is to provide light to see by. Some four or five years ago the Illuminating Engineering Society of North America - the IES - published "Lighting for health care facilities". The chairman of the IES committee which wrote this document was Dr. W.C Beck. He stated that:

> "the window today is viewed primarily as a psychological connection between the institutional environment and the outside world. Although such a glass opening does provide inside illumination, this is a secondary consideration (except possibly for the conservation of energy)."

The psychological connection, to which Dr. Beck refers, is particularly important in intensive care units and recovery rooms.

Kornfeld, in a paper published in the British Medical Journal made a number of suggestions for changes in hospital recovery rooms. One suggestion was that "an outside window should be visible to the patient". Three years later, in 1972, Wilson reported on a study to compare the incidence of post-operative delirium in two samples of surgical patients in Arkansas. There were 50 patients in each sample. One sample was nursed in an intensive care unit without windows and the other sample in an intensive care unit with windows. Over twice as many episodes of organic delirium were seen in the intensive care unit without windows. Further, there was an increased incidence of post-surgical depression in those patients in the windowless ward who did not develop post-operative delirium. The study concluded that it is highly desirable to have windows in an intensive care unit to prevent sensory deprivation.

Nowadays we find that the Ontario Ministry of Health strongly recommends windows in intensive care units. Moreover, I understand the U.S. Federal guidelines require that there must be access to windows in intensive care areas.

Contact with the outside is also particularly important in the cardiac care unit. In designing a CCU it is considered necessary to provide each patient a bed area with a window to provide a sense of orientation and well-being.

When talking about daylighting we are referring to the use and manipulation of visible light from the sun and sky. This light is made up of a band of colours - the spectrum - extending over just one octave from violet (350 nm) to red (700 nm). But the sun, of course, radiates energy in addition to visible light. It radiates, for example, cosmic rays; gamma rays; infrared rays; and, of particular interest to us, ultraviolet rays. Ultraviolet radiation can affect our health. Too much UV is bad for us: it can cause skin cancer. On the other hand, UV can produce desirable effects in our bodies. For example, it helps to synthesize the production of vitamin D, the vitamin which helps to make strong bones.

Conventionally, the Commission International de l'Eclairage (the CIE) divides the UV spectrum into three wavebands:

UV-A (near UV)	315-400 nm
UV-D (middle UV)	280-315 nm
UV-C (far UV)	100-280 nm

The shortest wavelength to which ordinary window glass is transparent is about 300 nm. Accordingly, a window glazed with that glass will let in no middle or far UV and only part of the near UV. The window will cut out most of the natural UV radiation from the sun - the radiation which is biologically active.

Years ago, the so-called "enriched" glass was developed. It had high UV transmittance and it was used in windows in sanataria. In more recent years interest in this glass has cropped up again.

For example, a review published by the World Health Organisation stated that the use of this glass was being evaluated in the USSR. The evaluation was under experimental conditions on laboratory animals and in full-scale use with children where the glass was used in windows. The WHO review reported that these windows are highly effective in their general health-giving influence.

In the United Kingdom a report published by the Department of Health and Social Security noted that windows made of glass which transmits UV radiation has been suggested as a way of improving the synthesis of vitamin D in elderly people who live in institutions and hospital wards as well as in ordinary homes. The report recommended, however, that more research is required before the use of UV transmitting glass could be advocated.

Through intensive study into the most effective window shapes and sizes for hospital wards was carried out about 25 years ago by Hopkinson when he was at the Building Research Station in England. Hopkinson investigated the relationship between window size, visual comfort and daylight factor. The daylight factor is the ratio between the illuminance at a point in an interior space to the illuminance from the unobstructed vault of the heavens. Hopkinson concluded the daylight factor at the back of hospital wards should not fall below 1% for the brightness distribution to be pleasant. A minimum daylight factor of 1% was accepted as a design criterion by the (British) Department of Health and Social Security. It was found to be possible to achieve this value in wards 7m (23ft) deep with a ceiling height of 3.05m (10 ft) without causing undue discomfort from sky glare to the patients in the beds nearest the window. This was done by the adoption of designs incorporating such features as the baffle used at Larkfield and Swindon Hospitals and the T-shaped window used at Musgrave Park.

Subsequently, the Department of Health and Social Security proposed to increase the number of beds in a given volume by raising the number in multi-bed bays from four to six. The depth of the bed-bay would be increased from 7m to 7.92m (26 ft) and the ceiling height reduced to 2.74m (9 ft).

Further studies at the Building Research Station, this time by Cockram and Collins, showed that large unscreened areas of glazing would be necessary to achieve the 1% daylight factor at the rear bed-spaces from side windows only. This would inevitably create problems of solar overheating and sky glare.

I mention these studies because I do not know of any comparable ones which have been undertaken in Canada. In my experience, most wards are 20 feet deep with two beds although I know of one recent hospital design with deep, four-bed wards. I understand that the fenestration for these wards is usually based on the 1978 "Measures for energy conservation in new buildings" developed by the Associate Committee on the National Building Code of the National Research Council of Canada.

These "Measures for Energy Conservation" set down empirical limits to the window area in buildings. In essence, the total area of glazing shall not exceed 15% of the floor surface area of the storey served by the glazed areas and also not exceed 40% of the total area of the walls of that storey. These limits permit a good deal of juggling of window shapes and sizes, while types of glazing and screening can also be juggled. Nevertheless, the limits have been based primarily on the requirements of energy conservation, and I would like to see a study undertaken to determine if windows designed to these limits have resulted in good ward lighting.

The publication "Light for health care facilities" which forms part of the Transactions of the Illuminating Engineering Society of North America devotes a column to daylighting. This starts off with:

> "The incorporation of some amount of fenestration appears essential in patients' rooms. The opportunity to look through windows, possibly at a pleasant view, is psychologically satisfying and permits relaxation when the eyes of patients, their visitors, and the hospital staff can occasionally focus on distant objects. However, arrangements which bring large areas of high luminance into the field of view can cause discomfort. Avoiding large differences in luminance between daylighted areas and interior areas illuminated to recommended levels is especially necessary. This may be accomplished by controlling the daylight rather than by increasing the level of electric illumination."

You will see that this refers to the problem of glare, a problem which was addressed by Hopkinson and his co-workers.

A patient lying on his back near an ordinary window is very likely to suffer from glare, especially on a cloudy day and even without seeing the sun. A cloudy sky gets brighter the nearer one looks straight up, and the patient looks more or less straight up. Some sort of daylight control device is necessary to screen the view of the bright sky from the patient, as we have already discussed.

Another point made in the same paragraph is the need for the patient to look through a window, " possibly at a pleasant view". The reference to a "pleasant view" should be particularly noted because all too frequently the windows provide a view out to an interesting scene for the visitor, but only a view of the sky for the patient.

For example, it has been noted that at the Harkness Pavilion of the Columbia Medical Center in New York City the patient has a dramatic view of the Hudson River - but only if he is able to get up and out of bed.

If a bed patient is to see out either the bed must be raised - which seems unlikely - or the window sill should be lowered - which should be considered. I have seen pictures of patients' rooms in U.S. hospitals in which the window comes down almost to the floor - just the thing, it would seem, to allow a patient to see what is going on outside. One such hospital is the Hospice for the Dying, in Branford, Connecticut, a hospital designed, to some extent, along the lines of those in medieval Europe. In those days the patient was placed so that he could see what was going on in the market outside.

However, hospital designers and psychologists both in Canada and the U.K. have pointed out to me that windows with low sills should not be used in hospitals - particularly on upper floors - since a feeling of insecurity is induced, particularly if a person is unwell. One distinguished psychologist with considerable hospital experience has drawn my attention to the fact that some people are scared to go on to a balcony because of that insecurity. For this reason he concluded that the window sill should be at its normal height of something in excess of 2 ft.

Nevertheless a proposal to the Daylight committee (TC 4.2) of the Commission Internationale de l'Eclairage by Dr. M. Seidl recommends that in sick rooms "a low top edge of window-sills is desirable to allow a sufficient view out. For that reason the window-sill's top edge should not be above bed-level (about 0.50m above floor level)."

I suggest that the optimum shape for windows in a patient room has not yet been settled.

We have discussed one paragraph of "Lighting for health care facilities". Now let us consider another.

> "The amount and distribution of daylight received in a room interior depends on the total area of windows, their light transmission properties, and the relationship of the window height to the room width."

Techniques to meet these considerations are, of course, well known, and we have seen the British use of a minimum daylight factor of 1% in 4-bed wards. It remains to be seen if this value is appropriate to the smaller Canadian wards.

Sun control may be necessary to cut down glare and heating effects. The study of sun control is a problem involving three dimensional geometry. It can be solved by computation, but is more usually solved by charts or sundial devices. Sundials are particularly useful for studies of shading and sun penetration.

The Heliodon is such a device. A lamp, representing the sun, shines on a model at angles corresponding to those at which the sun would shine on the actual building at corresponding times of day. The Heliodon is adjusted so that it corresponds to the sun's positions at any angle of latitude.

The Pilkington sundial and its French equivalent, the CSTB Diagrammes Solaires, serve the same purpose. A different sundial is needed for each 5°or 10° of latitude.

A number of myths have sprung up in lighting design. One was, of course, that the sun always shines from the top left hand side of the drawing board. More recently it was assumed that the sun is likely to pop up anywhere in the sky. As a result, sun control devices were used everywhere on a building. There is even one school - in Canada, north of the Equator - which has sun-shading louvres on its north side.

One method of controlling sun glare is, of course, the use of tinted or reflecting glass. I will come back to this subject a little later, but I wish to note here that the general practice seems to be to use glass of the same transmittance on all four sides of the building. I discussed this recently with the sales manager of a major glass company. He told me that he has always, without exception, provided the same glass for use throughout a building. The reasoning behind this practice seems, to me, to be cosmetic since the glass on the W facade will see a luminance which is approximately ten times that on the N facade. In fact, I have heard of one elegant apartment block with glazing that was apparently chosen with control of the sun glare in mind. Consequently, he glass has a low transmittance and, consequently, the north facing apartments are gloomy. The residents expected that continuity of space from the indoors, to the outdoors which was so much a part of Gropius' thinking. The residents do not have that continuity of space and they are objecting.

Different people in a hospital have different views on sunlight. In one study, 91% of the patients considered sunlight to be a pleasure; but, 62% of the staff considered it a nuisance. This difference is easily explained. Many of the patients were mobile, and they could move out of the sun if they so wished. As for the staff, many were working in fixed locations in a laboratory while the nursing staff were often engaged in quite heavy physical work. The sun caused a glare problem for the laboratory workers and a problem of thermal discomfort for the nurses.

"Lighting for health care facilities" refers to "the types of glass used in windows" and to the various types of heat absorbing and heat reflecting glass now available. Many of these glasses are not neutral in their light transmission characteristics - that is, they change the colour of the light as it passes through them. Evans, in a recent book, has recommended the use of grey reduced transmission glass since it does not distort the colour of the light. However, in my opinion, Cuttle has convincingly demonstrated that people prefer a non-neutral transmittance that gives a warm light. The actual change in colour is not noticed unless it is possible to compare a coloured window with one which is not coloured or with a view to the outside through an open window. However, here a question must be raised. Will the change in colour affect the ability of the doctor to use the patient's skin colour in diagnosis?

The question of colour change is, of course, one which crops up in selecting fluorescent lamps for hospital use. I have been in hospitals which seem somewhat unconcerned about the choice of lamp. In fact on Christmas Eve I was in a hospital which used Cool White lamps in the Emergency Ward. A discussion of lamps for hospital use is outside the scope of this paper although it is of interest to note that in th U.K. the colour specification for these lamps is laid down by the British Medical Association.

I have referred to windows that open. These have been specified for some years by the Ontario Ministry of Health for its hospital. The Ministry believes that a patient prefers to be able to open a window and thus control his environment, to some extent. The Ministry also believes that a window that opens can be used to provide cooling air should the HVAC system be shut down. Also, I have learned that the large openable windows in the newly opened St. Vincent's Hospital tower in New York City have been "enthusiastically received". It has been stated that the patient does not feel that he is cut off from the outside in a sealed chamber.

Five or six years ago, I raised a number of questions relating to hospital lighting. Let me quote those relating to daylighting.

1. What view out should be provided for a patient when he is lying down in bed, sitting up in bed, and ambulatory?

2. How can the view out be provided without excessive sky glare or direct glare from the sun and without creating a feeling of insecurity in the patient?

3. What is the optimum size, shape and type of window when the view out is weighed against heat loss and heat build-up through the window?

4. What is the optimum relationship between the window size, shape and type and the size (particularly the depth) of the ward to give an appropriate distribution of daylight in the ward?

I suggest that the questions are as valid today as they were when I first raised them. I am not the only person concerned with daylighting in hospitals. In August 1980, Health and Welfare Canada mounted a workshop on window design. At that workshop Carl Stein, the architect of New York City, stated

> "If what came out of this (conference) were that the next five hospitals built in Candada were done with a much more conscious point of view about window design, those buildings would be better and would also provide a cue to the design community that this kind of consideration will provide an architecture that will be considered more favourably."

I suggest that Mr. Stein's comments be taken to heart.

HOSPITAL LIGHTING DESIGN

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Introduction

Lighting design for health care facilities can involve the provision of illumination for over one hundred and twenty different tasks or activities.[1]

Lighting requirements can be separated into three broad categories; for patient care, for medical staff tasks, and for operational and administrative functions.

Patients benefit from lighting that creates a warm and cheerful atmosphere; lighting which is similar to the home environment.

Medical staff need adequate lighting, with very good colour rendition, suitable for each particular task requirement.

Operational and administrative staff lighting requirements are similar to those which are recommended for tasks and activities in commercial and institutional buildings.

Illuminance

Lighting levels recommended by the Illuminating Engineering Society of North America (IES) are similar to those recommended by the Commission Internationale de l'Eclairage (CIE). The lighting levels are divided into nine categories, each category provides a range of three illuminances, as shown in table 1.

For example, the IES recommends the following illuminance categories for patient rooms;

(a) general lighting, category B, (50-75-100 lux)
(b) patient observation, category A, (20-30-50 lux)
(c) critical examination, category E, (500-750-1000 lux)
(d) reading, by patient, category D, (200-300-500 lux)
(e) room cleaning, category C, (100-150-200 lux)

The IES Handbook[2] describes how to select the appropriate value of illuminance from the recommended category.

Lighting levels required for visual performance are not only illuminance criteria which needs to be considered. Lighting must also provide visual satisfaction, which is the subjective assessment of whether the lighting is pleasant, free from glare, and not too bright or too dark[3].

Lamps

Lamps are classified by their colour appearance and their colour rendition, their ability to render colours.

Colour appearance is specified by comparing the colour of the light source with an ideal black body radiator that is heated to the proper temperature in degrees Kelvin. The temperature at that the ideal black body radiator matches the colour of the light source is called the colour temperature of the lamp.

For example, an incandescent lamp, which has a reddish - white appearance, has a colour temperature of approximately 2800°K; a cool white fluorescent lamp, that has a white appearance, has a colour temperature of approximately 4200°K; and a daylight lamp, that has a bluish-white appearance, has a colour temperature of approximately 6500°K.

Lamps that have a colour temperature of less than 3300°K (reddish-white) are classified as "warm"; lamps which have a colour temperature between 3300°K and 5500°K are classified as "intermediate"; lamps which have (reddish-white) are classified as "warm"; lamps which have a colour temperature between 3300°K and 5500°K are classified as "intermediate"; lamps which have a colour temperature greater than 5500°K (bluis-white) are classified as "cool".

Warm lamps are best suited for lower lighting levels, below 700 lux; intermediate lamps are suitable for illuminances in the range of 700 to 3000 lux; cool lamps are more suitable for higher lighting levels, above 3000 lux. As a general rule, lamps with different colour temperatures should not be used in the same space at the same time.

Colour rendition is the ability of a lamp to render colours faithfully when compared to some suitable reference source such as daylight at the same colour temperature as the lamp.

One method of specifying the colour rendering ability of a light source is by the Colour Rendering Index (CRI). The CRI for lamps with a colour temperature below 5000°K uses noon daylight as the reference source, this reference source is given a value of 100. The CRI of a lamp which has "very good" colour rendition would be in the range of 90-100; a lamp with "good" colour rendition would have CRI between 70-90; a lamp with a CRI of 50-70 would provide only "fair" colour rendition.

The CRI of a lamp is determined by its ability to render the true colours of a number of saturated test colours, usually eight. Therefore two lamps, that have the same CRI value, may not necessarily render a particular colour (e.g. human skin) equally well. For applications that require very good colour rendition of an object, such as human skin or tissue, lamp selection should be made by actually observing the colour of the object when illuminated by the proposed lamp.

Some lamp manufacturers have proposed a new method of specifying the colour rendering properties of a light source based on the perceived colour of an object when illuminated by the lamp. This method, called the Colour Preference Index (CPI), has not been adopted by all of the major lamp manufacturers at this time.

Light Loss Factor

Lighting systems must be designed to ensure that the actual lighting level never falls below the recommended or design illuminance over the lifetime of the installation. The various reasons for the decrease in illuminance with use are combined into a single coefficient called the Light Loss Factor (LLF)[4]. Two of the most important reasons for the drop in light output are the decrease in lamp lumen output with use, called the Lamp Lumen Depreciation (LLD), and the decrease in luminaire output due to the accummulation of dust and dirt on the lamp and luminaire, called the Luminaire Dirt Depreciation (LLD).

To compensate for this anticipated drop in light output extra luminaires must be provided to maintain the lighting level at not less than the design level. These additional luminaires not only provide more light than is actually required over most of the life of the installation, but also, increase the capital cost and operating cost of the lighting system. The number of extra luminaires and the initial value of illuminance are directly related to the LLF as shown in figure 1. As the LLF decreases more luminaires are required and the capital and operating costs are also increased.

The capital and operating costs can be reduced by using a higher LLF than the actual design LLF and the ensuring that the depreciation of the lighting system does not drop below the selected value of LLF by using a planned maintenance program to upgrade the lighting system at regular intervals as shown in figure 2. The maintenance program would consist of replacing the lamps at regular intervals and cleaning the luminaires at the same time. The length of the maintenance cycle can be determined once the LLF has been selected. There are computer programs available which can calculate the optimum length of the maintenance cycle based on the minimum cost of owning and operating the lighting system. However, the LLF for most areas in health care facilities is more dependent on lamp aging than dirt accumulation on luminaires therefore the selected LLF can usually be based entirely on the loss of lamp output.

Dimming Systems

One way to minimize the operating costs and also keep the illuminance constant at the design value, in spite of the additional luminaires added to compensate for the anticipated loss of light output, is by dimming.

Dimmers can be manually or automatically controlled. Manual control requires a periodic adjustment of the lighting level; automatic control uses the output from a photosensor, which monitors the ambient light level, to hold the space illuminance at the design level. Some dimming systems can be programmed to provide different lighting levels for different task requirements in the same space.

Light output is almost directly proportional to power input over the dimming range. Therefore the power demand curve, as shown in figure 3, is the mirror image of the LLF curve shown in figure 1. Demand reduction will also provide a proportional reduction in energy consumption.

Dimming systems increase the capital cost of the lighting system; but, will save money by reducing the electrical demand and energy charges. The economic benefit of installing a dimming system can be determined by a Life Cycle Cost (LCC)[5] analysis. The LCC calculates the total cost of owning and operating the lighting system both with and without the dimming system.

Automatic dimming control can also be used to take advantage of any contribution to the space illuminance provided by daylight. This is particularly valuable during the summer months when the daylight component is high and any reduction in the electric illumination not only reduces the lighting cost; but also, reduces the load on the air conditioning system.

Conclusions

Lighting designers should take advantage of all of the most recent technological improvements in lighting equipment and design aids such as:

(a) improved high luminous efficacy light sources
(b) light sources with better colour rendition
(c) new high output fluorescent lamps and ballasts
(d) life cycle cost analysis computer programs
(e) lighting design computer programs
(f) manual and automatic dimming systems

The automatic dimmer control of lighting can be compared to the thermostatic control of heating. Dimming systems will become more widely used as energy costs rise and technical advances reduce the cost of dimming equipment.

Each lighting design should consider the use of dimming, where appropriate. This consideration should look at the benefits of having a lighting system with an adjustable lighting level, as well as, just the economic advantages, which may be marginal for some applications at the present time.

TABLE 1 Illuminance Categories and Values

CATEGORY	ILLUMINANCE - lux
A	20 - 30 - 50
B	50 - 75 - 100
C	100 - 150 - 200
D	200 - 300 - 500
E	500 - 750 - 1000
F	1000 - 1500 - 2000
G	2000 - 3000 - 5000
H	5000 - 7500 - 10000
I	10000 - 15000 - 20000

Categories A B & C are for general illumination
D E & F are for visual task illumination
G H & I are for special visual task illumination

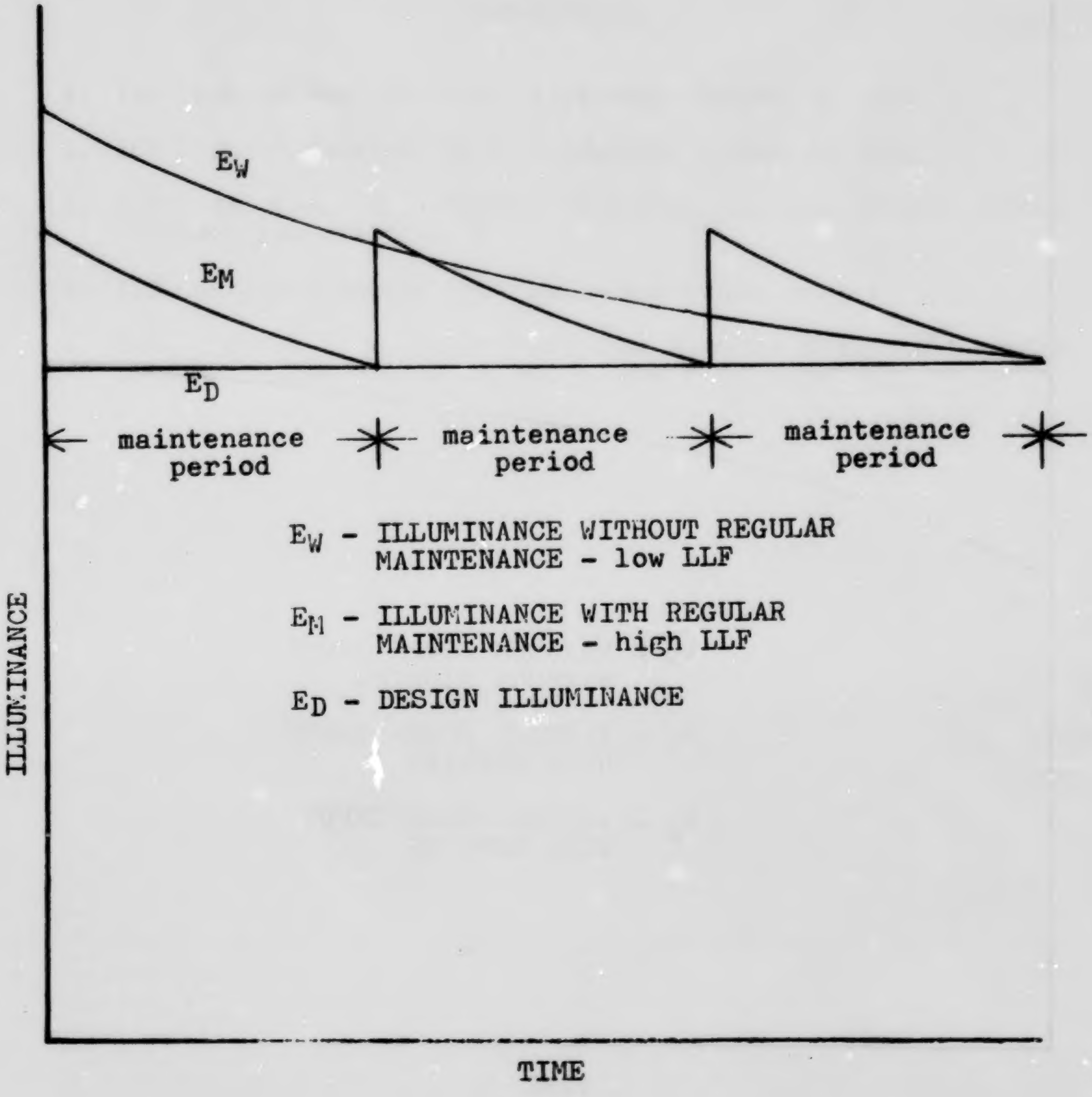

Fig. 2. DECREASE IN ILLUMINANCE WITH TIME, WITHOUT REGULAR MAINTENANCE AND WITH REGULAR MAINTENANCE

Note the decrease in the initial value of illuminance and installed capacity (for the same design illuminance) when the light loss factor is increased by a regular maintenance program.

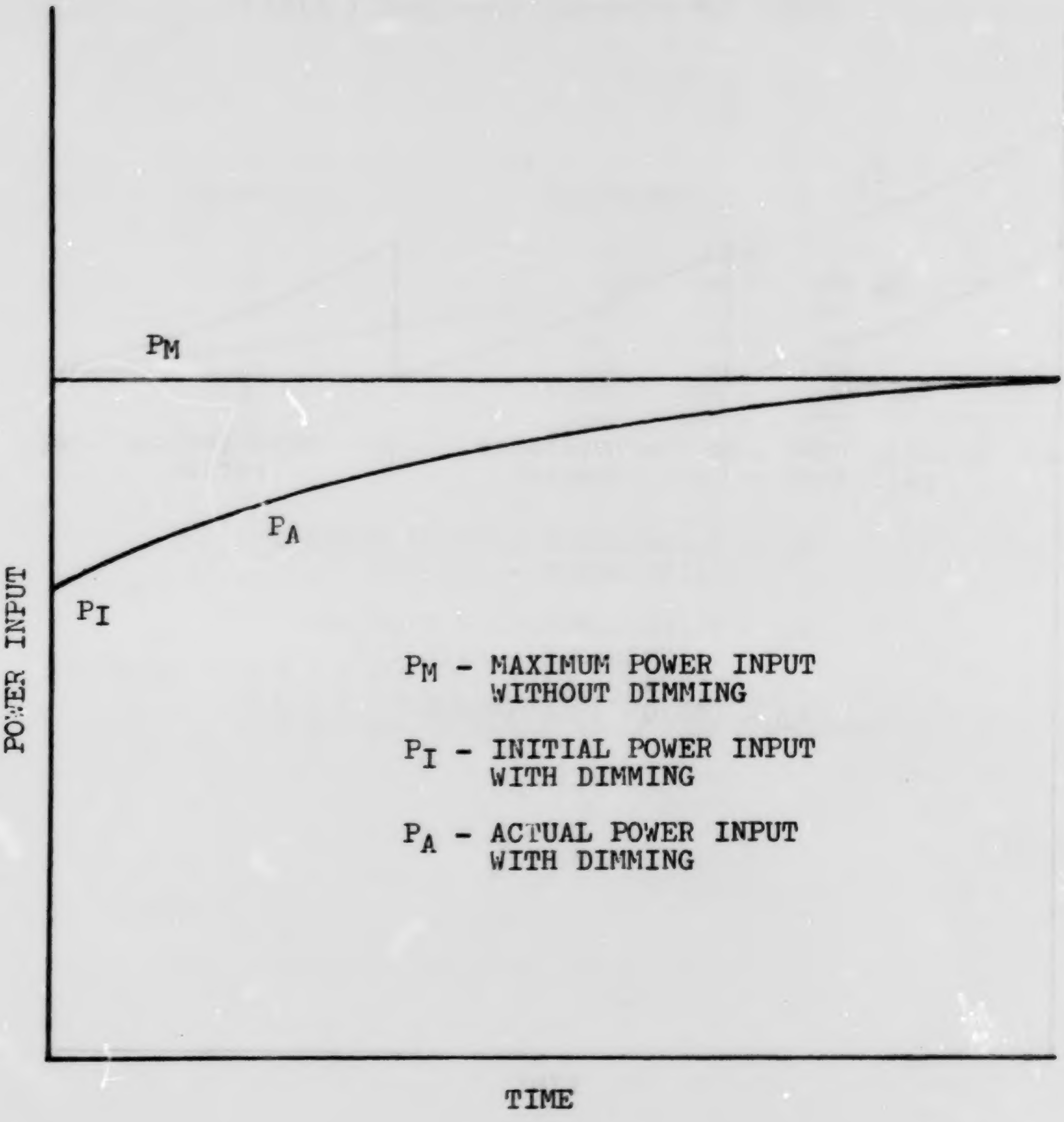

Fig. 3. POWER INPUT FOR A LIGHTING SYSTEM, WITHOUT DIMMING AND WITH DIMMING

Note that the actual power input curve is the mirror image of the actual light output curve in figure 1.

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LIGHTING STANDARDS AND CODES FOR HOSPITALS

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Introduction

It is indeed a pleasure to be participating in this symposium on "Lighting Design for Hospitals".

First of all, I would like to thank Mr. Harry Callan and his organizing committee for their kind invitation to make this presentation to-day on: "Lighting Standards and Codes for Hospitals". See figure 1.

The national health care system has over 22 million of potential users. The extent to which these people use the health care services vary with the age and sex composition of the population. For example children between the ages of five and fourteen average far fewer hospital days than the aged seventy-five years and over.

Health care services are provided by various types of institutions. Nationally, there are one thousand, three hundred and sixty (1,360) general public, special public, private and federal hospitals excluding the military ones. See figure 2.

The concentration of the hospitals is mainly found in three provinces, British Columbia, Ontario and Quebec which have more than 50% of the total number of hospitals. Ontario ranks first in number of hospitals, followed by Quebec. In Ontario there are (286) two hundred and eighty-six public hospitals which between them employ over 110,000 full-time and part-time staff. Each hospital is managed by a board through an executive director or president.

Hospital boards are autonomous and receive funding from the corresponding provincial ministry of health in accordance with provincial acts and regulations. Most of the hospital insurance programs began in 1958, and the medical insurance programs. See figure 3.

Were enacted approximately a decade later. By 1972 all the provinces in Canada had introduced medical care insurance programs.

Hospitals are classified, according to service provided, in three different ways: general, specialized and mental.

A General Hospital provides services for the diagnosis, treatment and care of all types of diseases to people of all ages.

A Specialized Hospital provides services for a specific group or limited range of diseases or restricts admissions to a particular age group or sex: such as a paediatric hospital which provides primarily for the diagnosis and short term treatment of paediatric patients.

A Mental Hospital provides treatment for all types of psychiatric conditions. See figure 4.

Hospitals, historically have been closely associated with charity and this is the reason that most of them are non-profit. From the 1,360 hospitals in Canada 1,163 are public hospitals. The health care system is regulated by various agencies with the provincial governments having primary jurisdiction over health matters and the federal government being an important source of financing.

Increases in payments, by the federal government, are linked to the rate of increase in Gross National Product, (GNP) thus providing the federal government with greater financial protection against rising health care costs. Each province operates an insurance plan and the current cost-sharing arrangements for direct federal payments are complicated and independent of the current cost of provincial plans. See figure 5.

For example, the expenditures of the Ontario Ministry of Health for 1980-1981 were approximately 4.9 billion. Fifty-eight percent of this amount was for hospitals and related facilities. Thirty-one percent for OHIP payments, five percent Direction Mental, etc.

The estimated budget for 1982-1983 is approximately six and a half billion or just below 29% of the Ontario governments budget.

The next transparency/slide shows the number of beds per Thousand population. See figure 6. Alberta has a relatively high number of hospital beds per thousand population when compared with the other provinces in Canada. Saskatchewan exhibits the second highest rates within the country, and Canada experiences a higher rate than the United States and other European countries. The reasons for these higher rates are due to a number of factors. Provinces with rural populations are spread over large areas; thus, citizens encounter transportation problems to the nearest centre particularly during the harsh winter months. These conditions encouraged rural senior citizens, in these provinces, to prematurely enter institutions for auxiliary hospital care, or as it referred to in this province, Chronic Care.

In all provinces the Ministry of Health or the Department of Health approves the construction or expansion of hospitals and provides capital funding. See figure 7.

Six of the provinces provide 100% financing. For example, in Alberta until 1973, the health units received eighty percent of their funding from the provincial government and twenty percent from municipal governments in their area. Since January 13, 1973, the arrangements changed and total funding has been assumed by the provincial government.

Nationally hospitals have approximately 192,000 beds or one hundred and ninety-two million square feet or twenty-nine billion dollars worth of property.

Constructing a new hospital is a lengthy and complex process. For example, for a 300 bed new public hospital, the time required from the master program stage to the final construction is approximately five years. See figure 8. Two and one-half years for design and approvals and another two and one-half years for construction.

New projects can be classified into four categories:
See Figure 9.

1. Operating cost only - No capital construction

2. Capital cost only - Replacement facility

3. Capital cost with operating cost implication

4. The hospital financing the capital cost with no additional operating cost.

In 1967, a hospital could be constructed with $28 per square foot. The 1983 figure is a $140 per square foot. See figures 10 and 11.

Thirteen percent of the total contract is assigned to the electrical cost and approximately ten percent of the electrical cost is used for lighting fixtures excluding the necessary branch wiring and lighting panelboards. See figure 12.

The lighting in hospitals is the second major block of consumption after the mechanical loads. The average consumption for an active treatment hospital is of the order of 15% of the total consumption.

The electrical cost for the Ontario hospitals was computed in relation to the floor area. The average minimum figure was of the order of 20 cents per square foot for electrical energy; 45 cents per square foot for heating; 5 cents per square foot for water. See figure 13.

The annual cost per bed per year will range at about $110,00 for electricity.

For those hospitals experiencing a high cost per square foot energy, management studies were initiated. Also, 19 implementations were carried out-to-date.

Codes-Standards and Guide

Regulations governing the design and levels of illumination in health care facilities are not only minimum but very limited. See figure 14.

Under the national building code, requirements are initiated at the technical level; but, provinces legally adopt the building code with or without modifications and the technical decisions become mandatory requirements.

The national building code of Canada is developed by the Associate Committee on the National Building Code of the National Research Council of Canada. Ten standing technical committees assist the Associate Committee on writing revisions to the Code. See figure 15. As you can see from these standing committees there is not a specific committee dealing with illumination systems in buildings.

Similarly, under the nine parts of the code there is not an assigned part to illumination. See figure 16. However, although there is a subsection 3.2.8, entitled lighting and emergency power systems. Under this subsection, sentence 3.2.8.1(1) sets the requirements for the intensity of illumination in corridors, including hospitals to 50 lux at floor level. See figure 17. Sentence 3.2.8.3 sets the intensity of illumination for emergency lighting at exits and corridors to 10 lux.

Another reference to lighting levels is made under table 9.3.5.2A. This table sets the minimum lighting for public areas in lux and in watts per square meter.

Subsection 3.1.11 interior finish sets specific requirements with respect to flame spread ratings for light diffusers and lenses. For example, a fixture with an aluminum parabolic louvre being non-combustible does not have to comply with all the requirements of subsection 3.1.11

The N.B.C. also makes reference to other codes and standards which in turn include some lighting levels; but, by no means provides complete information in the various departmental areas of a hospital.

Public buildings, in general, present various degrees of difficulty to design and manage. However, hospitals rank amongst the highest difficulty because in this type of building individuals receive care and treatment from other individuals. With changes in community requirements, the hospital services are modified accordingly and with technology advances a hospital faces constant change, making its position as a building unique and complex. Since a hospital houses a variety of departments whether specialized or supporting, it has a high concentration of staff and high population, consequently its design has to provide for these special needs with minimum obsolescence and maximum life expectancy.

The design of the illumination systems in a hospital also follows this philosophy.

Prior to the energy crisis, the lighting levels in hospitals were based on the values recommended in the lighting handbooks of the Illuminating Engineering Society of North America.

In some hospitals, the lighting load exceeded 4 watts per square foot and there were installations that after commissioning, the hospital staff removed as many as 30,000 fluorescent tubes. From a number of commissioned studies for energy management the recommendations were that the lighting levels can be reduced without functional or detrimental productivity effects.

The lighting levels recommended by the Illuminating Engineering Societies of the U.K., Sweden and Germany are generally lower than those levels recommended by the I.E.S. of North America.

A supplement to the building code dealing with energy conservation in new buildings indicates that for certain occupancies the lighting load shall not exceed 22 watts per square metre or 2.05 watts per square foot.

This is a substantial level and when efficient fixtures are selected and task lighting principles applied, 2 watts per square foot can provide 100 footcandles.

The next transparency/slide shows an approximate comparison of the lighting sources in common use. Luminaire selection shall be based on efficiency, photometric.

Distribution maintainability and cost. See figure 18. Also when selecting sources for health care facilities, more efficient sources shall be utilized. However, the use of high intensity discharge lamps (HID) should be restricted to service and public areas.

With these developments the Ontario Ministry of Health introduced recommendations early in 1976 which became a guide issued in 1979.

The design guide was initiated as a response to energy conservation practice in individual hospitals which shortly after the installation of new lighting systems proceeded to remove lamps from fixtures, disconnect fixtures or installed reduced wattage lamps in fixtures equipped originally with full wattage type of lamps.

Based on these findings and a number of studies carried out in existing facilities, as well as comparing lighting levels recommended by European societies new lighting levels were established.

The 1981 I.E.S. recommendations place the responsibility for the selection of the quantity and quality of light in the designer's judgement. It identifies a range of illuminance categories and also gives a limited number of lux/footcandle levels. The 1981 edition comprises two volumes, one reference and one application volume.

Other areas examined were the reflectances of surfaces. Light colour finishes which increase the utilization of artificial illumination are recommended. Reflectance measurements in a room can be determined using a footcandle meter. Results are accurate to about five percent which is close enough for normal lighting design work.

See figure 19. The two methods for field reflectance measurement are:

1. The reflected/incident light method and
2. The known sample, comparison method.

The ratio of the reflected to the indicent light gives the approximate reflectance figure.

The other major area of change from traditional designs is the use of higher maintenance factor. The recommended maintenance factor in the guide is 85% compared with 60 to 70 percent used normally. This resulted in much higher initial footcandle levels which drop to the recommended level at the end of the lamp life. The lighting source normally used is a fluorescent luminaire and a voltage change of 2½ percent in supply voltage affects the output of the fluorescent luminaire by one percent unlike the incandescent sources whose output is affected by 3 percent when the supply voltage changes by 1% from the rated voltage of the lamp.

There are five basic factors to be taken into consideration for a good lighting system.

1. Brightness
2. Contrast
3. Glare
4. Specular and Diffuse Reflection of Surfaces
5. Colour

Research into glare problems and tasks which are subject to veiling reflections introduced ESI - equivalent square of illumination which is the usuable footcandles in a room as opposed to the raw footcandle measure. ESI measurements require elaborate and expensive equipment which is not of practical use for field measurements. For this reason, indirect photoelectric measurements of ESI were developed. Both the direct and the indirect measurement techniques require the physical presence of a reference task.

As a comparison 73 raw footcandles will give an ESI level of 30 footcandles.

The hospital building comprises a variety of lighting requirements which require individual treatment.

A patient room requires a general average ambient lighting level of 20 footcandles and another task level of 30 footcandles.

The hospital bedlight, as seen figure 21, provides these levels adequately, since the level for reading is met and the reading light area allows the patient sufficient freedom to turn in bed without moving out of the reading light zone.

At the bed location there is also a requirement for an examination light which should provide an average of 70 footcandles.

This examination light, as seen in figure 22, should not spill light affecting others in the room and should be confined to the bed area of the patient being examined.

Further solutions for this kind of application will be discussed later on to-day by Mr. Leipciger under "experience reports".

Metric Changes and New Developments

Another change that is being faced in the lighting designs is the metric fixture and the metric fluorescent tube. In new hospital buildings this does not present any problem since a metric dimensions fixture 300 X 1,200 millimeters and a metric lamp nominal 1160 millimeter are specified.

It must be noted that the 1160 millimeter tube is another new dimension other than the European international lamp which is 1050 millimeters. See figure 23.

The metric tiles are either 600 X 1200 millimeters or 300 X 1200 millimeters. This is the systems international S.I. and it replaces the imperial system, 12 X 48 inches fixture and the 2' X 4' or 1' X 4' tiles. This is an effective module especially when the five by five module was broken into three 20 inch by 60 inch, thus allowing three positions to rotate the fixture as well as it can be rotated by 90 degrees. The fixture changed to 14 X 48 inches with fillers to make the 60 inches either built-in as part of the fixture finish or added on site by the acoustical trade.

For additions to existing hospitals with metric layout ceilings. Metric/imperial fixtures are used. The fixture dimension is in metric but the spacing of the lamps is for imperial measure tube. This reduces the types of lamps to be stocked and avoids confusion in existing facilities.

Ballasts in the fluorescent fixtures are also changing from the core-coil type to electronic types. With one ballast we can supply a 2-lamp, a 3-lamp or a 4-lamp fixture. The electronic ballasts use transistor circuitry to rectify the A.C. 60 cycle.

Supply to D.C. and then invert it back to a sinusoidal A.C. 10 to 20 kilocycle/second wave. With the increased frequency the lamp efficacy is increased by almost 12%. However, in hospital applications, caution must be exercised in order to avoid interference effects on electromedical equipment.

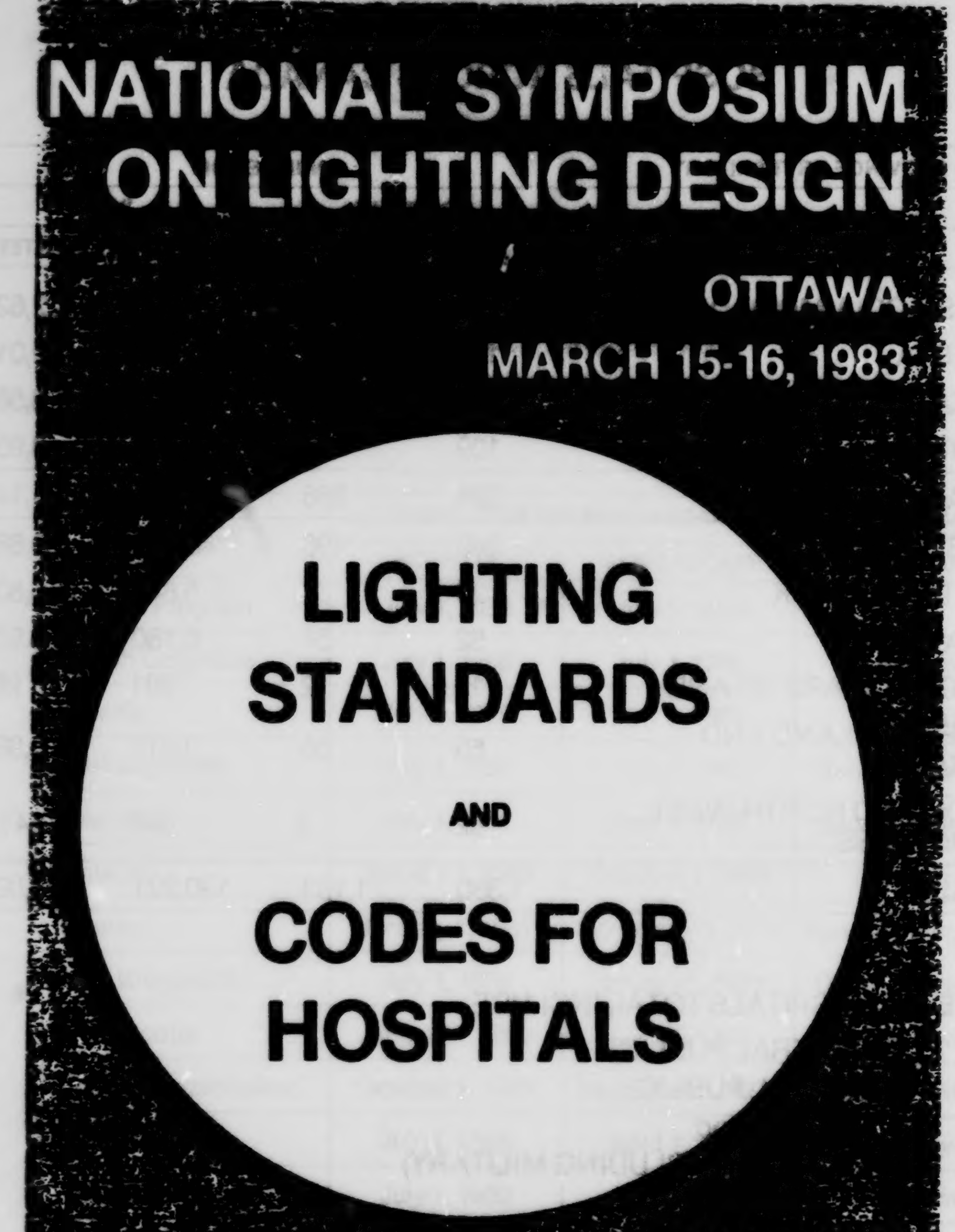
The cost of the electronic ballasts is presently three times over the cost of the standard ballast and two times over that of the efficient core type.

Other Developments in Progress:

1. Is the more efficient incandescent which is coated and reflects heat onto the filament thus using less energy.

2. Lighting control with sensors which detect human presence in the room using infrared technology and research by Ontario Hydro and Honeywell on a fibre optics switch.

Concluding, I would like to point out that the illumination systems in buildings are becoming more complex, as seen in figure 24, and the selection of sources and controls increasingly more difficult.



NATIONAL SYMPOSIUM ON LIGHTING DESIGN

OTTAWA
MARCH 15-16, 1983

LIGHTING
STANDARDS
AND
CODES FOR
HOSPITALS

A PRESENTATION BY
LAKIS ELLINAS P. Eng., C. Eng., MIEE
SENIOR ENGINEERING CONSULTANT

Fig. 1. LIGHTING STANDARDS AND CODES FOR HOSPITALS

HOSPITALS ACROSS CANADA

PROVINCE OR TERRITORY	NUMBER OF:			
	HOSPITALS		BEDS	
	*TOTAL	PUBLIC**	SET UP	RATED
BRITISH COLUMBIA	151	132	22,698	22,626
ALBERTA	169	162	20,266	20,013
SASKATCHEWAN	144	141	8,603	8,582
MANITOBA	109	88	9,308	8,956
ONTARIO	328	286	63,363	64,140
QUEBEC	249	196	48,695	50,689
NEW BRUNSWICK	39	37	5,647	5,639
NOVA SCOTIA	52	51	6,180	5,972
PRINCE EDWARD ISLAND	12	12	981	980
NEWFOUNDLAND AND LABRADOR	55	55	3,917	3,987
YUKON AND NORTH WEST TERRITORIES	52	3	543	541
TOTALS	1,360	1,163	190,221	192,025

*NOTE — HOSPITALS TOTAL INCLUDE:
GENERAL PUBLIC,
SPECIAL PUBLIC,
PRIVATE and
FEDERAL (EXCLUDING MILITARY)

**NOTE — HOSPITALS PUBLIC INCLUDE:
GENERAL PUBLIC and
SPECIAL PUBLIC

Fig. 2. HOSPITALS ACROSS CANADA

REFERENCE: 1981 CANADIAN HOSPITAL DIRECTORY

PROVINCIAL HOSPITAL AND MEDICAL CARE INSURANCE PROGRAMS

PROVINCE	INSURANCE PROGRAM BEGAN		MEDICAL CARE INSURANCE FINANCING METHOD
	HOSPITAL	MEDICAL CARE	
Federal Program	July 1, 1958	July 1, 1968	—
British Columbia	July 1, 1958	July 1, 1968	Premiums
Alberta	July 1, 1958	July 1, 1969	Premiums
Saskatchewan	July 1, 1958	July 1, 1968	General Revenue
Manitoba	July 1, 1958	April 1, 1969	General Revenue
Ontario	January 1, 1959	October 1, 1969	Premiums
Quebec	January 1, 1961	November 1, 1970	Special Payroll Tax
New Brunswick	July 1, 1959	January 1, 1971	General Revenue
Nova Scotia	January 1, 1959	April 1, 1969	General Revenue
Prince Edward Island	October 1, 1959	December 1, 1970	General Revenue
Newfoundland	July 1, 1958	April 1, 1969	General Revenue
Yukon Territory	July 1, 1960	April 1, 1972	Premiums
Northwest Territories	April 1, 1960	April 1, 1971	General Revenue

Fig. 3. PROVINCIAL HOSPITALS AND MEDICAL INSURANCE PROGRAMS

HOSPITAL CLASSIFICATION

1. ACCORDING TO SERVICE PROVIDED

- General
- Specialized
- Mental

2. TYPE OF OWNERSHIP

- Public
- Private
- Federal

3. TYPE OF OPERATOR

- Provincial
- Federal
- Municipal
- Religious
- Private
- Red Cross

Fig. 4. HOSPITAL CLASSIFICATION

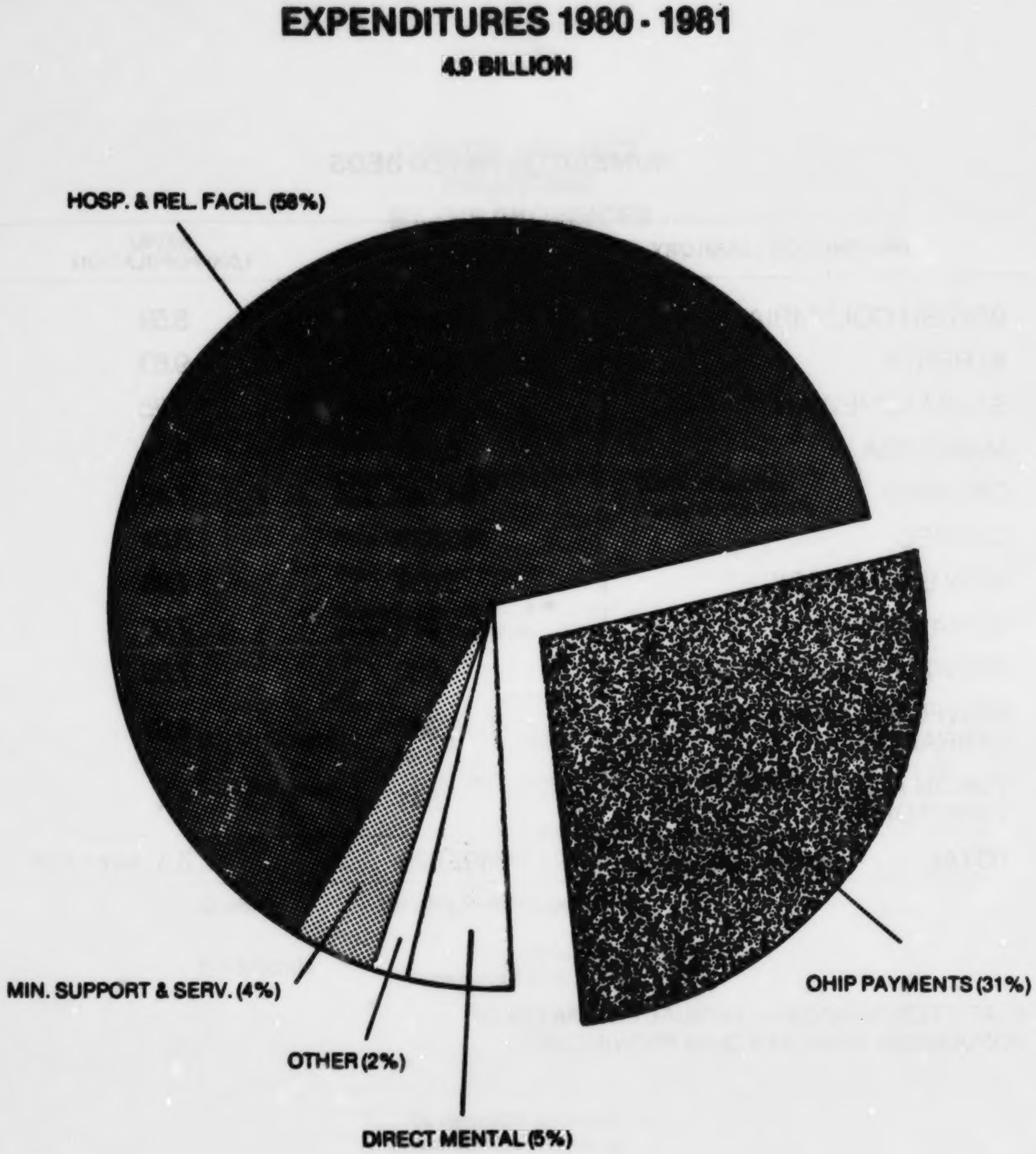


Fig. 5. EXPENDITURES 1980-1981

ESTIMATED BUDGET FOR 1982 - 1983

HEALTH
$6,579 BILLION

PUBLIC HOSPITALS
$3.2 BILLION

NUMBER OF RATED BEDS

PROVINCE OR TERRITORY	NO. OF BEDS	BEDS/ 1,000 POPULATION
BRITISH COLUMBIA	22,626	8.59
ALBERTA	20,013	9.63
SASKATCHEWAN	8,582	8.86
MANITOBA	8,956	8.71
ONTARIO	64,140	7.48
QUEBEC	50,689	8.04
NEW BRUNSWICK	5,639	7.98
NOVA SCOTIA	5,972	7.00
PRINCE EDWARD ISLAND	980	7.89
NEWFOUNDLAND AND LABRADOR	3,987	6.87
YUKON AND NORTHWEST TERRITORIES	541	8.4
TOTAL	192,025	8.3 AVERAGE

STATISTICS CANADA — ANNUAL ESTIMATES OF POPULATION FOR CANADIAN PROVINCES

Fig. 6. NUMBER OF RATED BEDS

CAPITAL PROJECT FINANCING BY THE PROVINCES

Northwest Territories
Alberta
Manitoba
Ontario Teaching Hospitals Only
New Brunswick
Prince Edward Island
Newfoundland
(Directly to the Contractors)

100% of capital construction costs

British Columbia	60%
Saskatchewan	50%, 60%, 70%
Ontario	2/3 Hospital 1/3
Quebec	Variable Percentage
Nova Scotia	80% Community 20%

Cost sharing government/hospital

Government approvals for new construction in all provinces

Fig. 7. CAPITAL PROJECT FINANCING BY THE PROVINCES

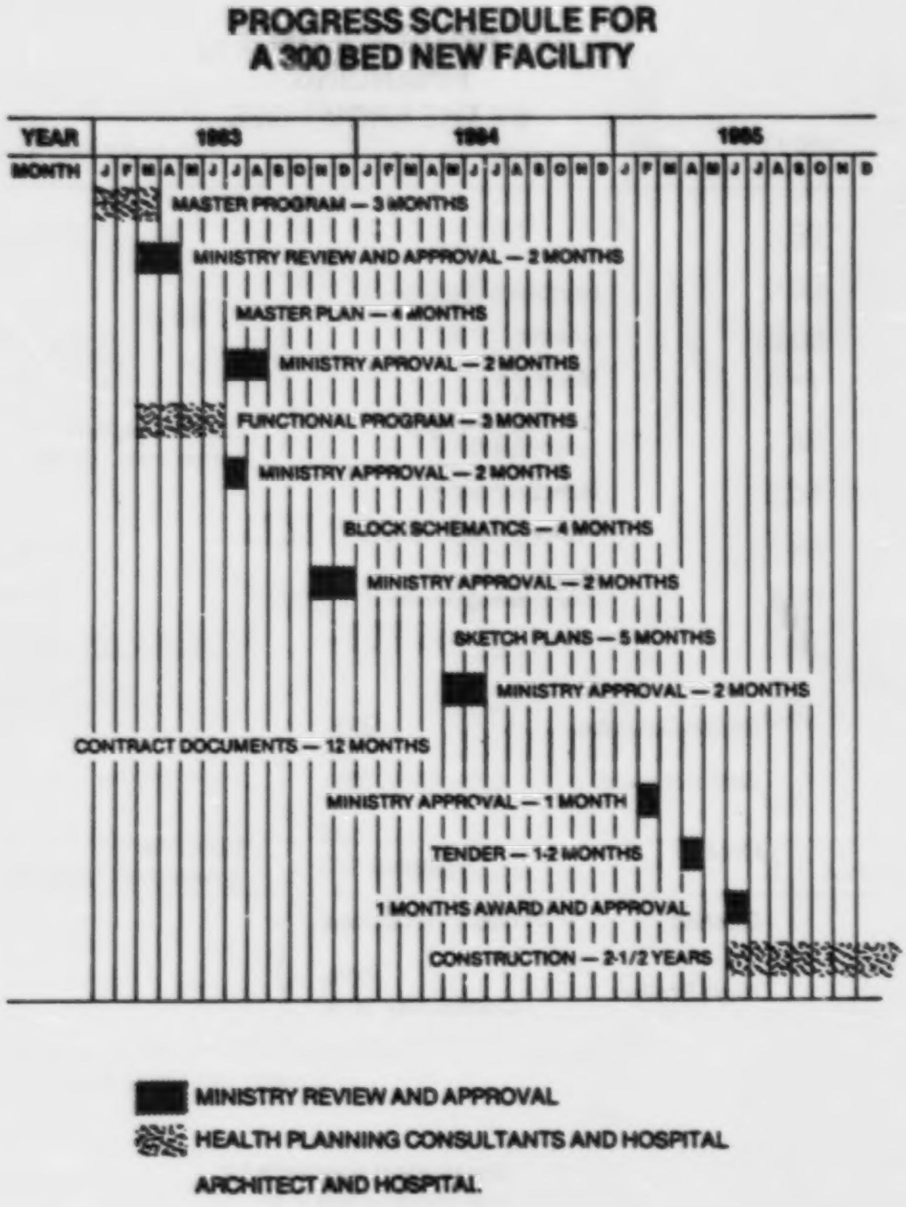


Fig. 8. PROGRESS SCHEDULE FOR A 300 BED NEW FACILITY

NEW PROJECTS CLASSIFICATION BY COST

OPERATING COST ONLY

CAPITAL COST ONLY

CAPITAL WITH OPERATING COST IMPLICATION

HOSPITAL OWN FUNDING
NO EXTRA OPERATING COST

Fig. 9. NEW PROJECTS CLASSIFICATION BY COST

CONSTRUCTION COSTS SKYROCKET

YEAR	COST/SQUARE FOOT	
	TOTAL	ELECTRICAL
1967	$ 28.00	$ 3.00
1968	$ 31.00	$ 4.00
1969	$ 33.00	$ 4.50
1970	$ 36.00	$ 5.00
1973	$ 40.00	$ 6.00
1978	$ 56.00	$ 8.00
1979	$ 80.00	$ 9.00
1980	$ 85.00	$ 9.50
1981	$ 95.00	$11.00
1982	$110.00	$12.00
1983	$140.00	$14.00

Above costs exclude:

- **Movable equipment**
- **Aquisition of land**
- **Organization costs by the hospital**

Fig. 10. CONSTRUCTION COSTS SKY ROCKET

AVERAGE BREAKDOWN OF ELECTRICAL CONSUMPTION IN A HOSPITAL

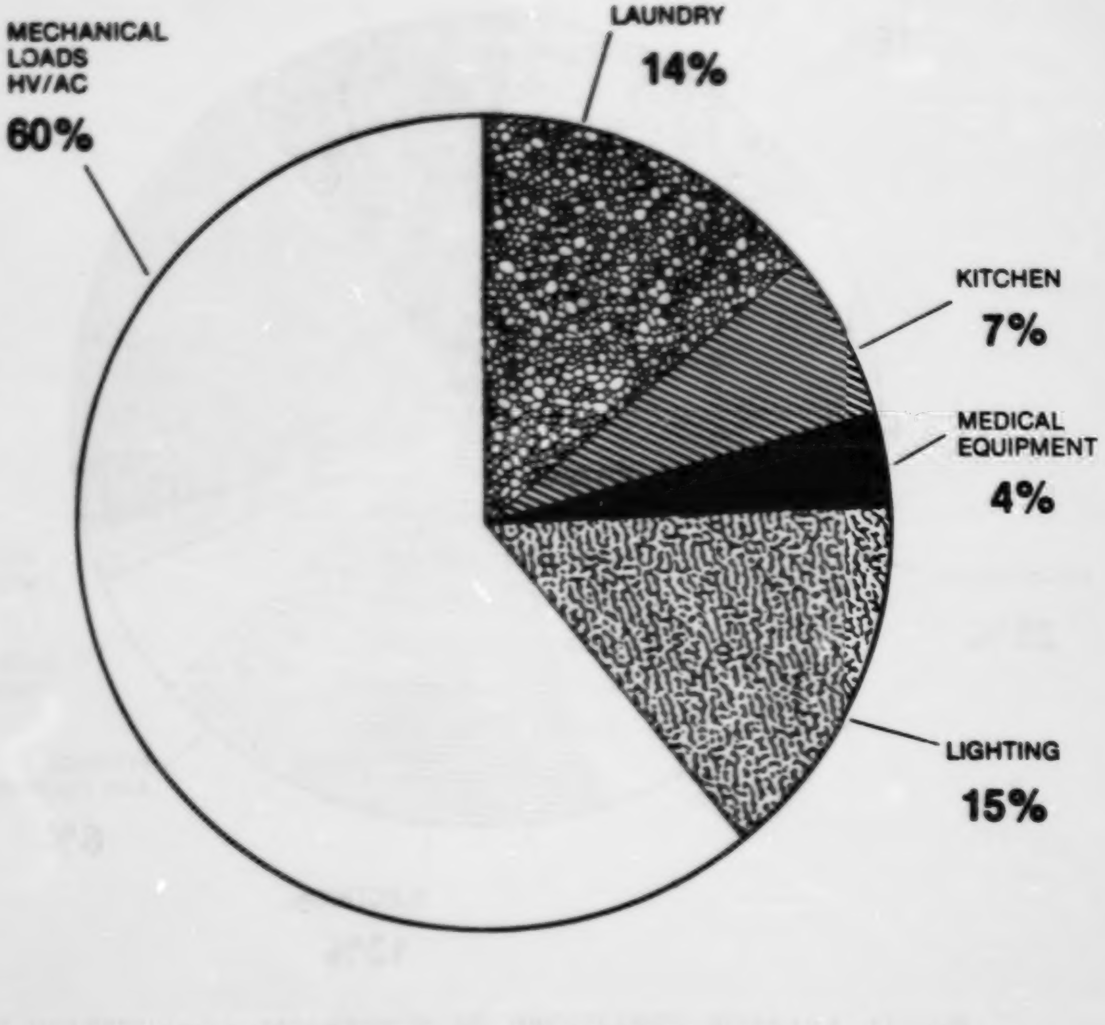
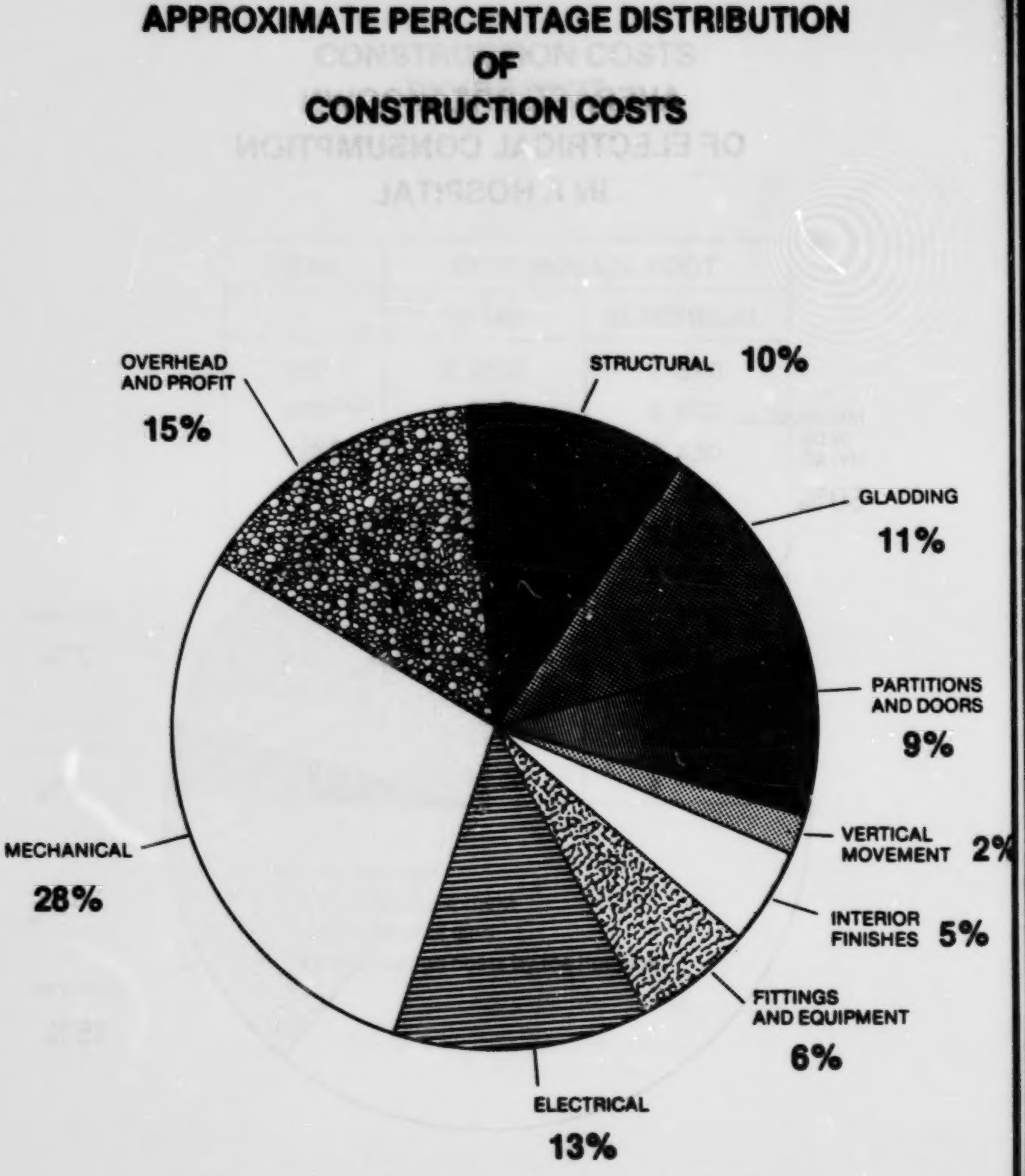
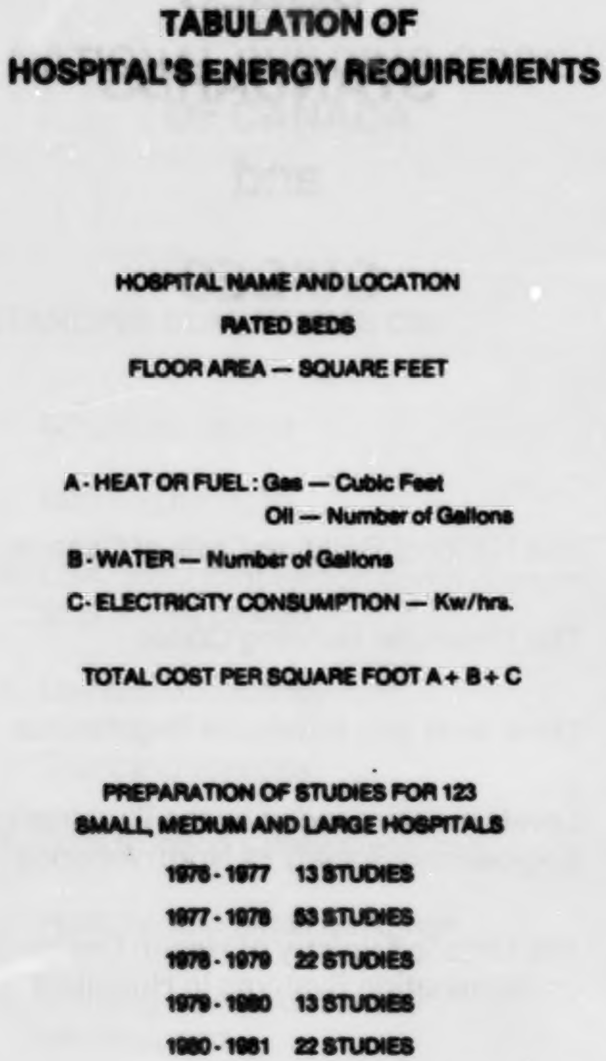


Fig. 11. PERCENTAGE DISTRIBUTION OF CONSTRUCTION COSTS



APPROXIMATE PERCENTAGE DISTRIBUTION OF CONSTRUCTION COSTS

Fig. 12. AVERAGE BREAKDOWN OF ELECTRICAL CONSUMPTION IN A HOSPITAL



TABULATION OF HOSPITAL'S ENERGY REQUIREMENTS

HOSPITAL NAME AND LOCATION

RATED BEDS

FLOOR AREA — SQUARE FEET

A - HEAT OR FUEL : Gas — Cubic Feet
Oil — Number of Gallons

B - WATER — Number of Gallons

C - ELECTRICITY CONSUMPTION — Kw/hrs.

TOTAL COST PER SQUARE FOOT A + B + C

PREPARATION OF STUDIES FOR 123 SMALL, MEDIUM AND LARGE HOSPITALS

1976 - 1977	13 STUDIES
1977 - 1978	53 STUDIES
1978 - 1979	22 STUDIES
1979 - 1980	13 STUDIES
1980 - 1981	22 STUDIES

Fig. 13. TABULATION OF HOSPITAL'S ENERGY REQUIREMENTS

CODES
STANDARDS
and
GUIDES

1. The National Building Code of Canada
2. The Provincial Building Codes
3. Other Acts and Provincial Regulations
4. Levels recommended by the Illuminating Engineering Society of North America
5. The Ontario Ministry of Health Design Guide on Illumination Systems in Hospitals

Fig. 14. CODES STANDARDS AND GUIDES

1980
NATIONAL BUILDING CODE OF CANADA

STANDING COMMITTEES ON:

1. Structural design
2. Building services
3. CSA/NBC joint liaison committee on limit states design
4. Use and occupancy
5. Plumbing services
6. Construction safety measures
7. Housing and small buildings
8. Building standards for the handicapped
9. Farm building standards
10. Fire performance ratings

Fig. 15. STANDING COMMITTEES

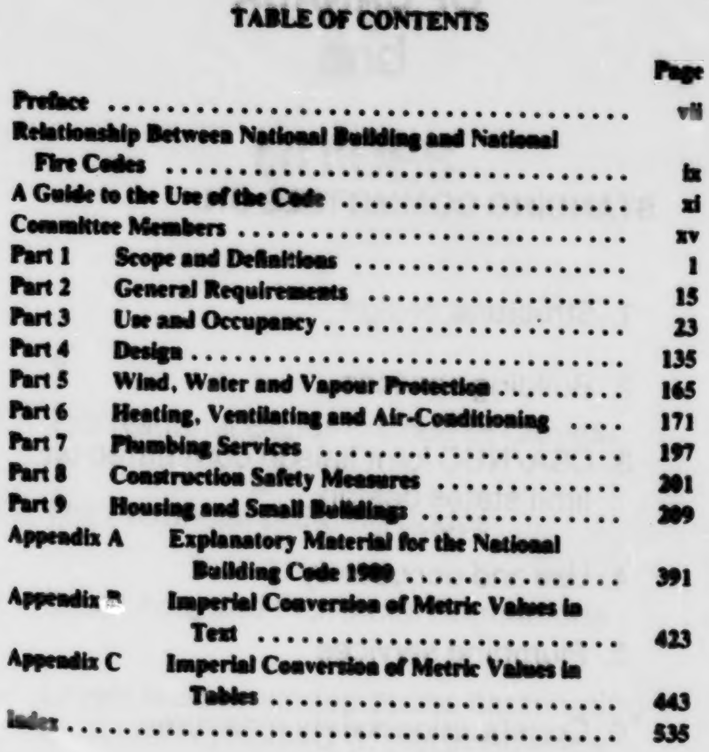


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Fig. 16. PARTS ON N.B.C.

1980
NATIONAL BUILDING CODE
OF CANADA

SUBSECTION 3.2.8
LIGHTING AND EMERGENCY POWER SYSTEMS
(Page 97)

3.2.8.1.

(1) Every exit, public corridor, corridor providing access to exit for the public or serving patients' bedrooms or classrooms shall be equipped to provide illumination to an average level of at least 50 Lux at floor level and at all points such as angles and intersections at changes of level where there are stairs or ramps.

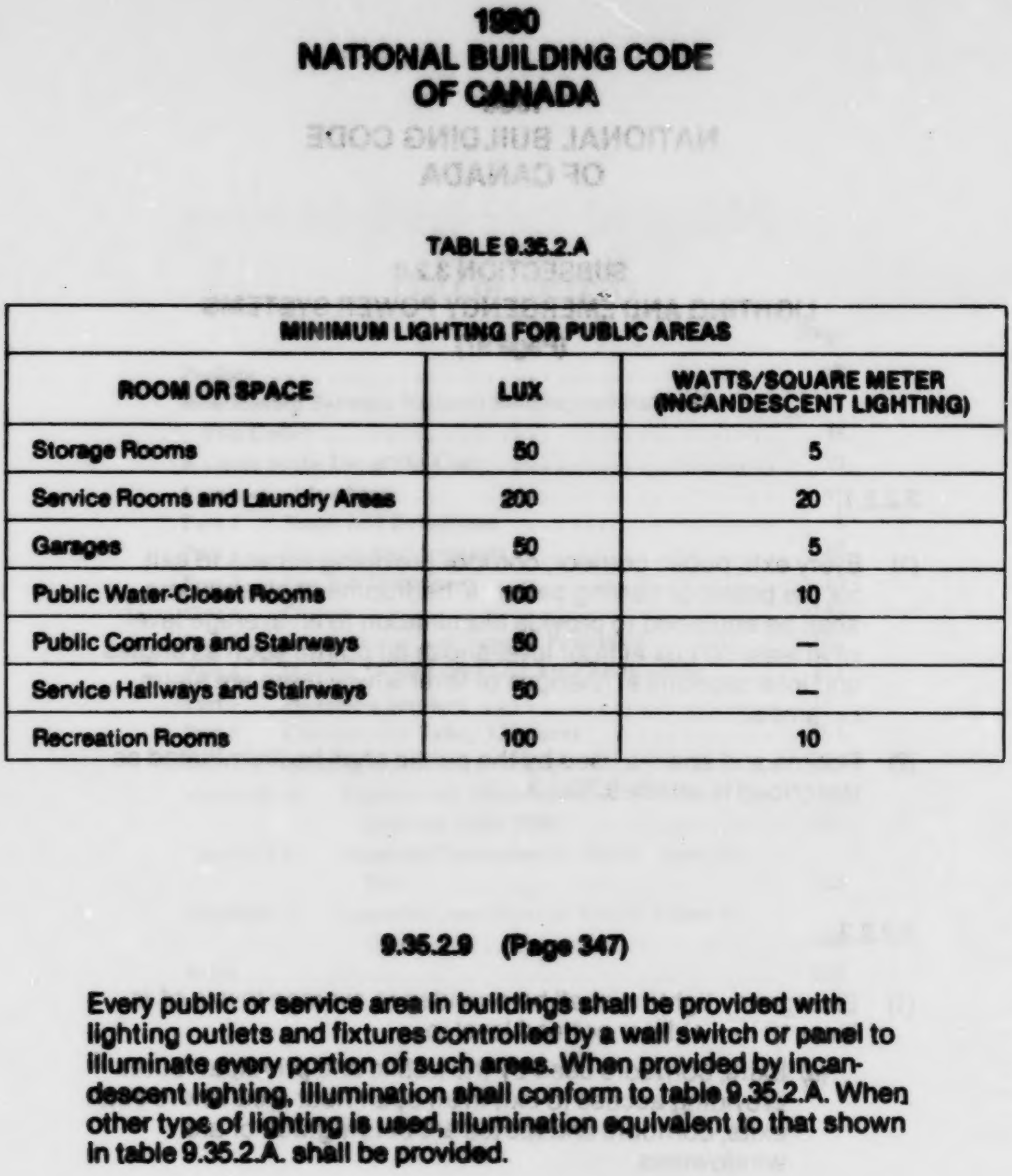
(2) Rooms and spaces used by the public shall be illuminated as described in article 9.35.2.9.

3.2.8.3.

(1) Emergency lighting shall be provided to average levels of at least 10 Lux at floor or tread level in

  (a) Exits, corridors used by the public and principal routes providing access to exit in an open floor area where such exits, corridors and routes are below grade or are windowless.

Fig. 17. SHOW TRANSPARENCY



1980
NATIONAL BUILDING CODE OF CANADA

TABLE 9.35.2.A

MINIMUM LIGHTING FOR PUBLIC AREAS		
ROOM OR SPACE	**LUX**	**WATTS/SQUARE METER (INCANDESCENT LIGHTING)**
Storage Rooms	50	5
Service Rooms and Laundry Areas	200	20
Garages	50	5
Public Water-Closet Rooms	100	10
Public Corridors and Stairways	50	—
Service Hallways and Stairways	50	—
Recreation Rooms	100	10

9.35.2.9 (Page 347)

Every public or service area in buildings shall be provided with lighting outlets and fixtures controlled by a wall switch or panel to illuminate every portion of such areas. When provided by incandescent lighting, illumination shall conform to table 9.35.2.A. When other type of lighting is used, illumination equivalent to that shown in table 9.35.2.A. shall be provided.

Fig. 18. ESTIMATING CHART

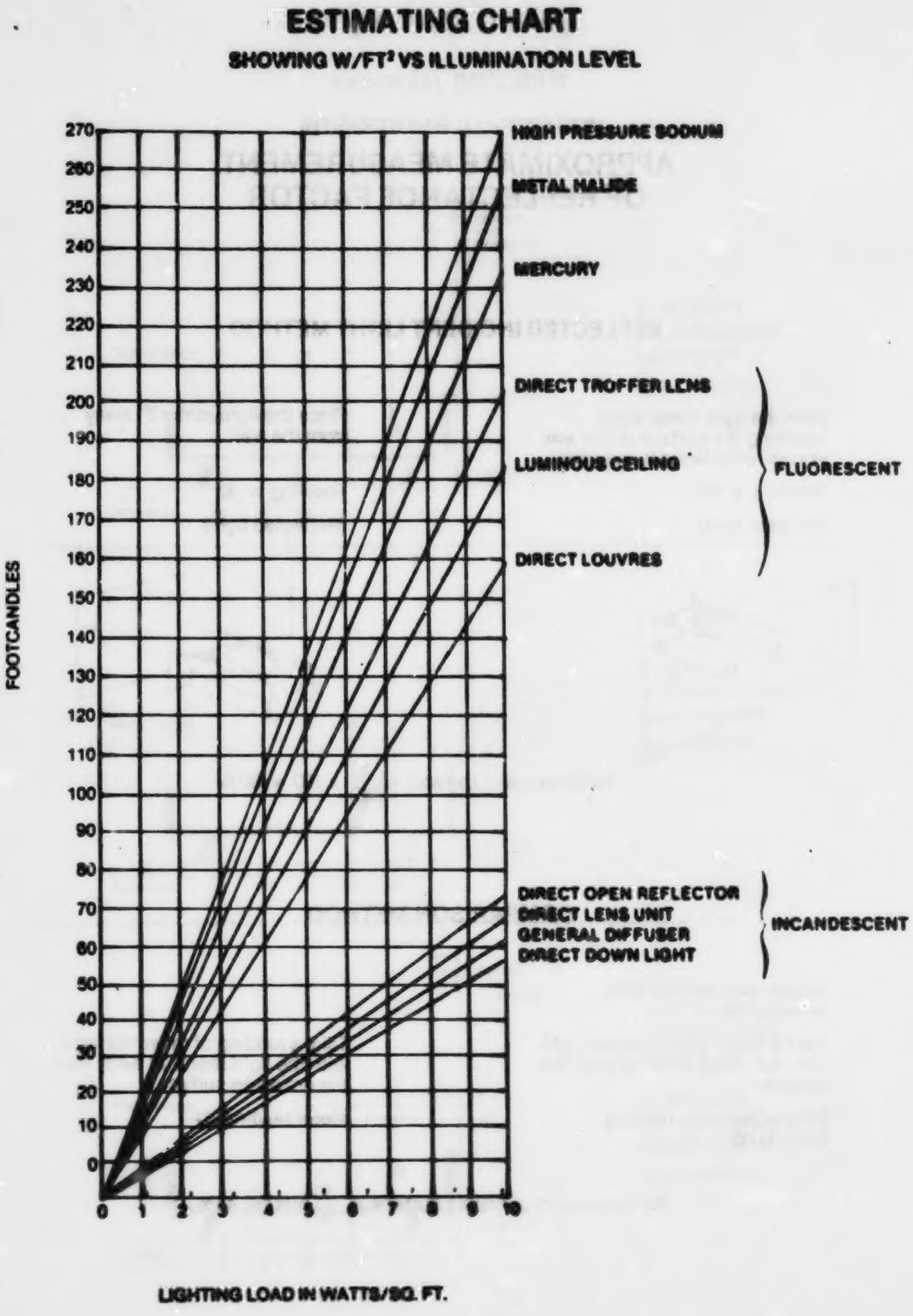


Fig. 19. APPROXIMATE MEASUREMENT OF REFLECTANCE FACTORS

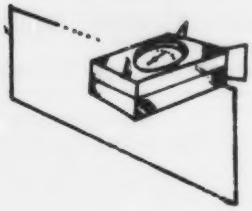
APPROXIMATE MEASUREMENT OF REFLECTANCE FACTOR

REFLECTED INCIDENT LIGHT METHOD

With the light meter base touching the surface of the wall whose reflectance is required.

Reading = 40

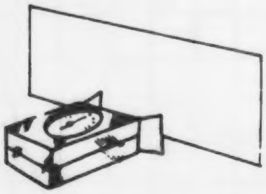
(Incident light)



Place the light meter 2" away from the wall

Reading = 32

(Reflected light)



Reflectance of the wall = $\frac{32}{40} \times 100 = 80\%$

COMPARISON METHOD

Known sample with 90% reflectance

Take a reading of reflected light with the meter 2" away from the sample.

90% reflectance reading taken is 60

Take a reading of reflected light with the light meter 2" away from the unknown surface.

Meter reading 30

Reflectance of unknown surface = $\frac{30}{60} \times 90 = 45\%$

Fig. 20. APPROXIMATE MEASUREMENT OF REFLECTANCE FACTORS

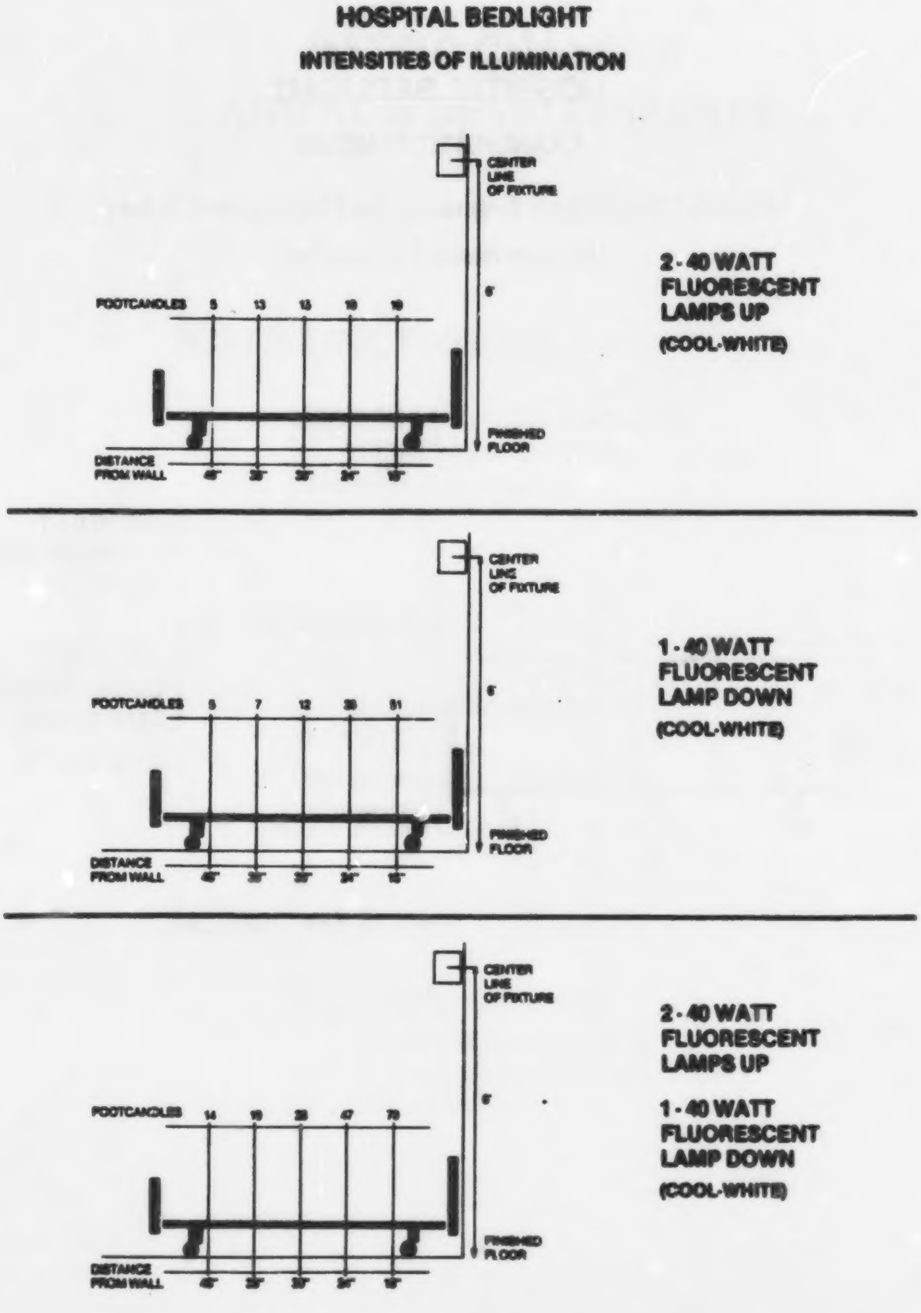

HOSPITAL BEDLIGHT
INTENSITIES OF ILLUMINATION
CENTER LINE OF FIXTURE
6'
FOOTCANDLES 5 13 15 19 19
FINISHED FLOOR
DISTANCE FROM WALL 46" 38" 32" 24" 16"
2-40 WATT FLUORESCENT LAMPS UP
(COOL-WHITE)
CENTER LINE OF FIXTURE
6'
FOOTCANDLES 5 7 12 28 51
FINISHED FLOOR
DISTANCE FROM WALL 46" 38" 32" 24" 16"
1-40 WATT FLUORESCENT LAMP DOWN
(COOL-WHITE)
CENTER LINE OF FIXTURE
6'
FOOTCANDLES 14 19 28 47 70
FINISHED FLOOR
DISTANCE FROM WALL 46" 38" 32" 24" 16"
2-40 WATT FLUORESCENT LAMPS UP
1-40 WATT FLUORESCENT LAMP DOWN
(COOL-WHITE)

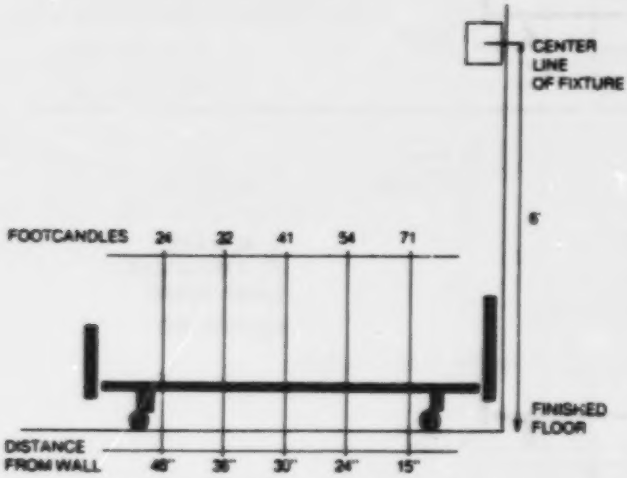
Fig. 21. HOSPITAL BEDLIGHT INTENSITIES OF ILLUMINATION

HOSPITAL BEDLIGHT

EXAMINATION MODE

Fixture Lifted Open Exposing the Fluorescent Tubes

(Up and Down Lamps On)


CENTER
LINE
OF FIXTURE
6'
FOOTCANDLES
24
32
41
54
71
FINISHED
FLOOR
DISTANCE
FROM WALL
45"
36"
30"
24"
15"

2 - 40 WATT FLUORESCENT LAMPS UP

1 - 40 WATT FLUORESCENT LAMP DOWN

(COOL-WHITE)

Fig. 22. HOSPITAL BEDLIGHT EXAMINATION LIGHT

METRIC CHANGES AND NEW DEVELOPMENTS

SOFT METRIC FIXTURES

Uses 48 inch tube and is an imperial fixture with the numbers converted to metric

METRIC/IMPERIAL

The fixture dimension is in metric.

The tubes are imperial.

METRIC FIXTURES

The fixture dimension is in metric and take only metric type lamp 1160 mm long F40 CW or WW.

Fig. 23. METRIC CHANGES AND NEW DEVELOPMENTS

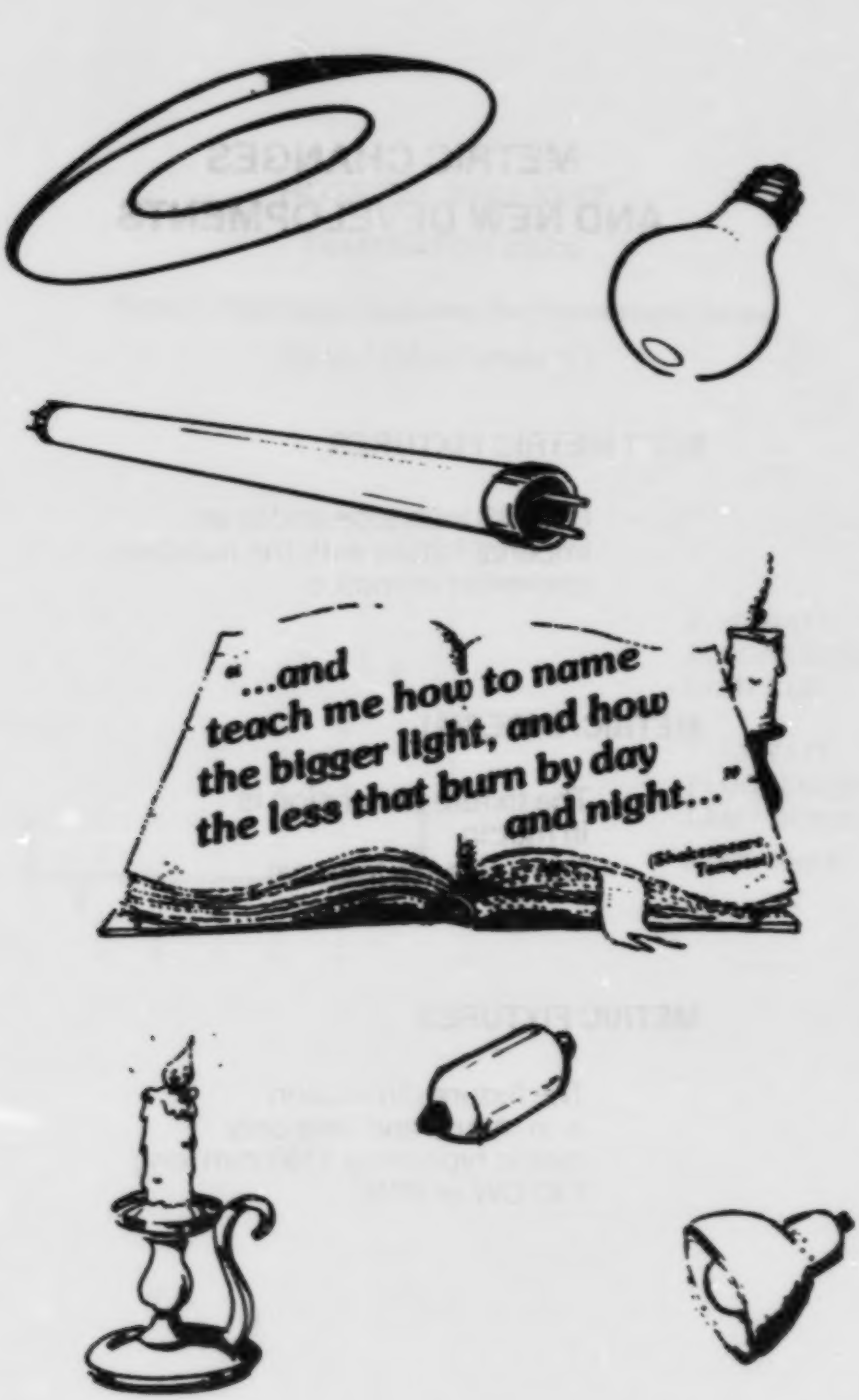

"...and
teach me how to name
the bigger light, and how
the less that burn by day
and night..."
(Shakespeare, Tempest)

Fig. 24. TEMPEST

"ENERGY MANAGEMENT IN HOSPITAL LIGHTING"

A. Levy Ph.D.
Director of Marketing & Development
Engineering Interface Ltd.
Willowdale, Ontario

Introduction

The purpose of this paper is to present:

- (a) the context in which a lighting energy management projects takes place
- (b) the energy management process
- (c) an example of that process
- (d) an example of the magnitude of the savings that can be achieved

Hospital Energy Management

Electricity and fuel costs in hospitals are typically between 2% and 5% of total operating budgets.

Total energy costs range between $1 per sq. ft. and $4 per sq. ft. Energy costs are therefore significant and will remain so even if oil prices do not escalate in double figure percentage points over the next few years.

Energy management is all about efficiency: efficient production, efficient transmission and efficient use, see Figure 1.

Before trying to improve efficiency, however, hospital managers need to know how much and where energy is currently being used. An energy audit is required. An audit by itself is not sufficient unless it is accompanied by some analysis to identify which building systems are not operating at maximum efficiency and economy.

Most hospitals consume about half of their energy in heating, ventilation and air conditioning. Laundries and lights consume another 10% to 20% each with the remaining distributed amongst food services, sterilizers, incinerators and medical equipment.

To embark upon a lighting energy management program in isolation of or independent of the other building systems is not recommended.

It is recommended:

- (a) that lighting be considered part of a planned energy

management program, with an objective in terms of an energy target (or budget)
(b) that priorities are set
(c) that a proper energy monitoring system be in place

The Energy Management Process

The energy management process has three essential phases (see Figure 2):

(a) Audit and Analysis
(b) Action Program
(c) Monitor and Review

The Audit and Analysis provides:

(a) a description of the building energy use patterns
(b) the amount of energy being used in particular building systems
(c) an energy target; not only for the entire hospital but for the major energy systems also
(d) the size of the potential savings
(e) a plan to obtain the savings, including the timing of energy management measures and how they will be implemented.

The Action Stage is where human and financial resources are applied in a systematic way to save money for energy costs.

Monitor tracks the performance of the Action Stage against previous energy use and the target.

Energy targets are not new to energy engineers and consultants. The problem in the past is that they have been high in cost and low in credibility as a result of the indiscriminate use of computer simulation programs.

Over the last decade both government and private enterprise have been collecting data on energy use. Both conservation successes and energy waste. This data can be stored and manipulated in energy use databases. The databases provide the foundation for new energy target setting procedures which have credibility by using real data collected in real buildings.

The 1980's will see the emergence of energy targets as the new objective for energy management. Previously too many programs have suffered in motivation and performance from vague and poorly substantiated percentage reductions. Motivation declines because the percentage savings decreases each year, whereas targets become closer and closer and have to be maintained.

A Case Study - The Process, The Savings

In November 1982, Health and Welfare, Canada selected 22 similar hospitals from Saskatchewan, Manitoba, Ontario, New Brunswick, Nova Scotia, Newfoundland and Prince Edward Island to attend a unique two-day workshop in Toronto.

The workshop was unique in that:

(a) upon arrival at the workshop each hospital received an Audit of its own facilities and a Group Audit comparing all 22 hospitals

(b) both an administration and hospital engineer attended from each hospital

(c) energy targets were set by the hospitals themselves

(d) an action plan was committed to

(e) the cost savings potential was quantified in the presence of the two parties (administrator plus engineer) so essential to a successful energy management program.

At the end of the two days, the hospitals which in total had an annual energy consumption of 1,600,000 ekWh/sq.ft./yr had identified an annual energy savings potential of 16% or 254,000 ekWh/sq.ft.

Actual energy costs stood at $8,400,000 with a savings potential of 18% or $1,500,000.

The one and one half million dollar savings were distributed as follows:

(a) 44% in fuel which did not respond to seasonal weather variations. i.e. domestic hot water, kitchens etc.

(b) 31% in electrical demand and consumption i.e. lighting and fans

(c) 25% in weather-sensitive fuel use such as heating and building envelope performance.

Lighting and fans can be seen as a most significant area for cost savings. The most common "cures" for energy waste such as insulation and double glazing contribute to the small 25% figure.

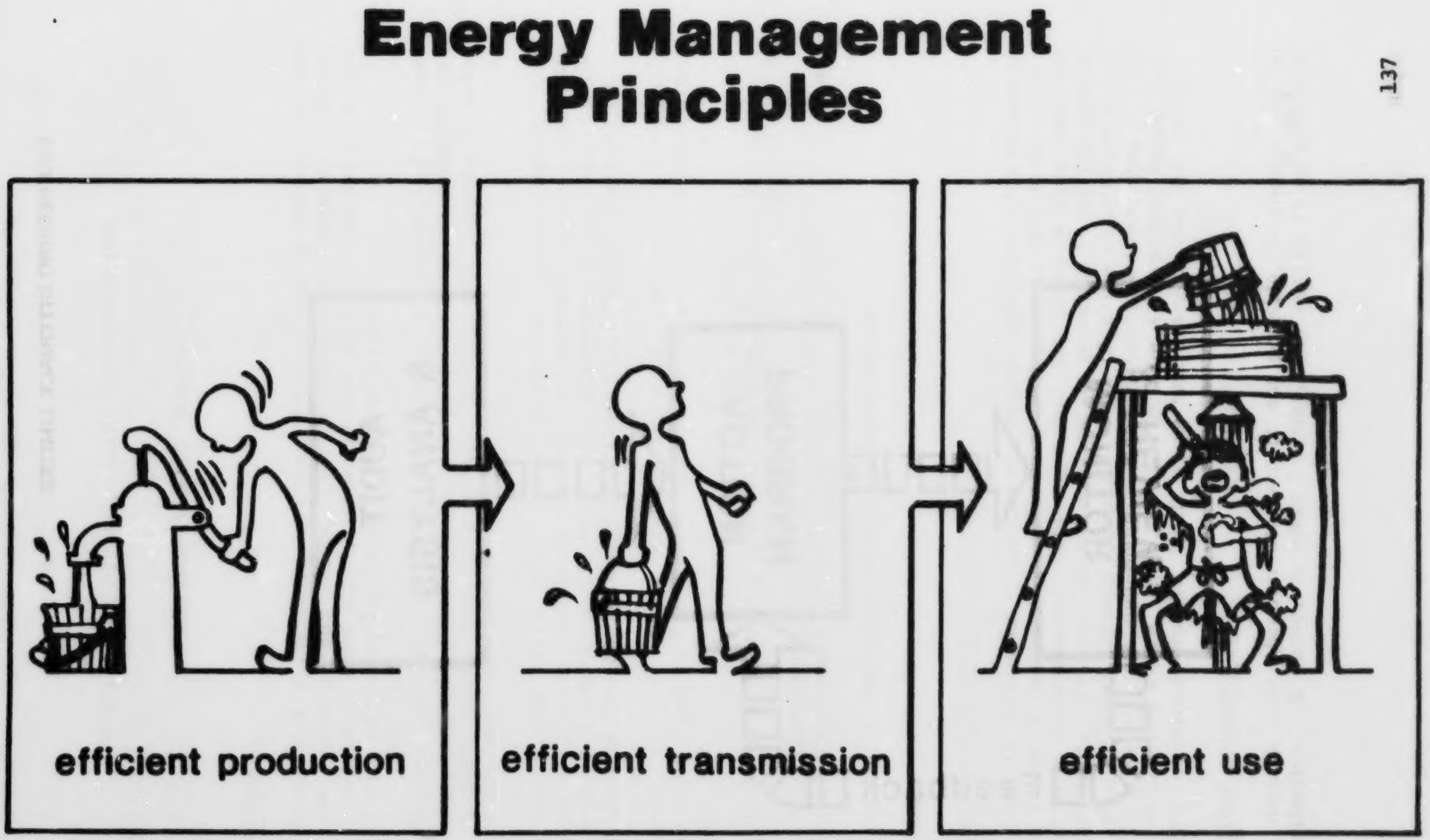
The lesson is clear.

Document what you have.

Understand why energy is being used in the quantities it is.

Remember that the primary purpose of the facility is patient care.

Take systematic steps to reduce waste and save money, monitoring and reviewing each re-design or retrofit measure.



Energy Management Principles
efficient production
efficient transmission
efficient use

Fig. 1

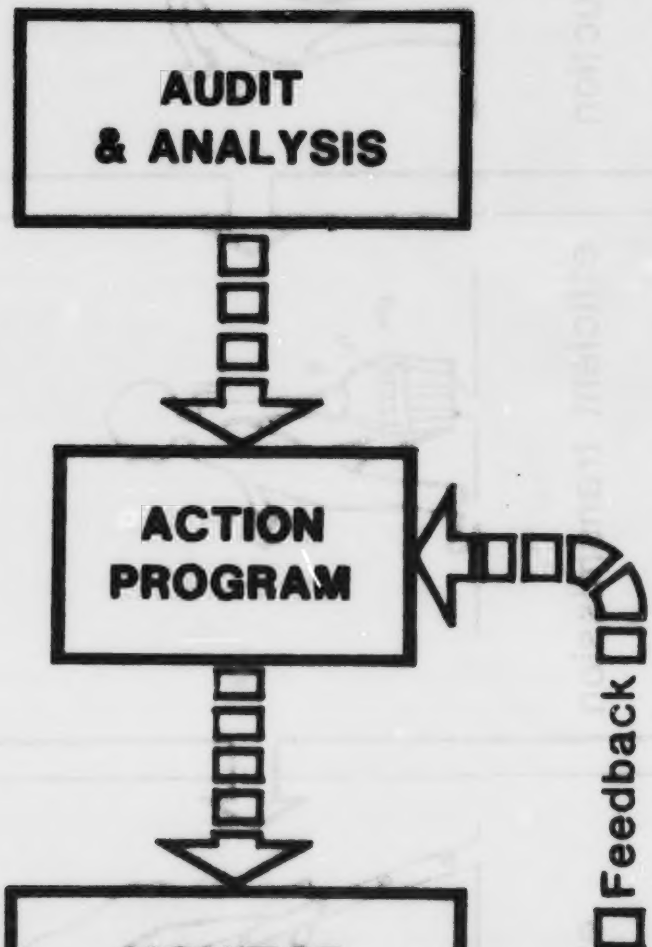

AUDIT
& ANALYSIS
ACTION
PROGRAM
MONITOR
& REVIEW
Feedback

Fig. 2

HOSPITAL LIGHTING: NURSING CONCERNS

Marjorie Daechel, Reg.N.

Introduction

I appreciate this opportunity to communicate to you a nurse's feelings about the successes and inadequacies of lighting in hospitals. Hopefully, I will be of some help to those of you who are interested in and involved with providing appropriate hospital lighting.

My background consists of direct patient care in surgery and obstetrics. My comments today will be based on my own experiences and those of other nurses who have worked directly with patients in other areas of the hospital.

In my thirty odd years since I first began my nursing career, I've witnessed a dramatic change in the lighting provided in hospitals. We have evolved from dimly lit halls and stairwells of the past to the bright glare of fluorescent lights in virtually all areas of the hospital.

As nurses, our concern is good patient care. We cannot adequately achieve this goal if we have either insufficient or inappropriate lighting.

I will divide my observations into two categories:

(a) Successes
(b) Weaknesses

In conclusion, I enumerate several recommendations.

Successes

(a) Natural light through windows

On the list of successes - the use of natural light through windows in patient rooms is number one. Windows give patients and staff alike a freedom from confinement. Even on a dull day there is little need for artificial light. This use of natural light is provided in all the patient rooms at the Ottawa General Hospital. It is of prime importance to the patient's psychological well-being. When patients are confined to bed for days or even weeks, they are able to have a rewarding visual contact with the outside world. Their whole time frame is not disrupted.

(b) Other natural light

Where natural light through windows is not possible, skylights can be very effective. A nurse, to whom I spoke, had worked in an intensive care unit which was windowless, but had a sky light in the centre of the room. She beamed with enthusiasm when she talked about this. She said that both patients and staff really enjoyed the sky light - day and night - all seasons of the year. This design was at the Concordia Hospital in Winnipeg.

Patients in an intensive care unit are often restricted in their movements with monitors and intravenouses. Through a skylight, they have a feeling of contact with the outdoors and do not lose the concept of day and night, a problem which often occurs in a windowless room. Such contact provides a tremendous psychological effect on the patients, thus making an important contribution to their recovery.

(c) Flexible lights

The third success is the use of flexible lights. For example: goose neck lamps which can be used at the head of the patient's bed for the patient's benefit. This light can be adjusted by the care provider in such a way that it gives adequate lighting for delivery of patient care without unduly disturbing other patients in the room.

(d) Good lighting in nurse's work area

The provision of good lighting in the nurse's work area constitutes the fourth success. For instance, a light directly over the medicine cupboard where good lighting is essential. The desk where charting is done also requires such lighting. At the Ottawa General, recessed lights provide such lighting without glare.

A sink in the patient's room with a light directly over the sink area is convenient for both the patient and the nursing staff.

(e) Lighting in hospital lounge areas

Next in the success category is the provision of lighting in hospital lounge areas, particularly the cafeteria, where visitors, staff and ambulatory patients come for relaxation. The cafeteria at the new Ottawa General, provides a very relaxing environment. This is due largely to the two walls of windows that give it such a bright airy atmosphere by day. At night it is still relaxing and comfortably lit, with rows of recessed ceiling lights which give ample light without glare.

Weaknesses

At the root of many of the lighting inadequacies in hospitals, is the inappropriate use of high density lights. The more recent concept of using fluorescent lights, creates in many instances, a glare which reflects off the white linen and light coloured walls. The problem of light reflection on white linen was recognized approximately thirty years ago when operating rooms changed all their linen, doctors' gowns, drapes, table covers etc. to a dark green or blue, to reduce glare on the operating field.

(a) Fluorescent Lights

The practice of installing direct flourescent lights on the wall over the patient's beds, provides good lighting for the patient to read by and for the nurse to deliver patient care. However, when a nurse or a doctor has to deliver care to one patient in a multi-patient room, the light over that patient disturbs the other sleeping patients because of the amount of light that is reflected around the room.

In rooms where the patients condition requires a darkened room, nurses have been known to put green plastic pads over the lights. These pads, although they reduce the light, are a fire hazard. They are used because the nurse is able to get adequate light for her functions without disturbing the patient. Fluorescent lights controlled by dimmer switches give at minimum, an eerie light which does not provide adequate lighting for the delivery of patient care.

Nursing alcoves, common to certain hospital designs, are often lit with fluorescent ceiling lights for nursing functions. These alcoves usually lead directly into the patients' rooms. At night, when the patients' door is opened, the light floods in disturbing the patient who is sleeping.

The nurse also has to allow time for her eyes to adjust to the darkened room when going from the high density light into the dark room.

In one instance, the nursery nurses found that fluorescent lights in the nursery, though more than adequate, give babies a bluish tinge. This is very important because nurses are watching the babies closely for any change in colour. This was such a problem that during the day the nurses would often have to take babies to the window to accurately assess their colour.

The nurses, complained of headaches from the lighting. The regular fluorescent bulbs were changed to "day light" bulbs and there was a significant change in the ability to assess the babies colour. The nurses no longer complained of headaches.

In the emergency department, the nurses to whom I spoke complained of the headaches they experience while working in a nurses station area completely lit with fluorescent lights. They say the lights are too bright - probably too much glare reflects from the light coloured ceiling, walls, floors and desk.

In the trauma rooms where patients are admitted for emergency care, the small rooms are lit with four fluorescent ceiling lights. By switch control, two fluorescent lights at a time can be used. Even with the minimum amount of light that is provided by these two fluorescent lights, the light is often still too bright for patients who are admitted complaining of severe migraine headaches. These and other very ill patients find the bright ceiling lights very irritating.

The operating room holding area, 18' X 22', is equipped with nine fluorescent ceiling lights. This is the room where the patients are brought prior to being taken to the operating room where the surgery will be performed. These patients have usually been given a pre-operative sedation to help them to relax in this stressful situation. The patient is drowsy from the medication and is more relaxed in a dimly lit room. The staff is able to function with only one fluorescent light which is over a doorway, not directly in the patient area.

In operating rooms, the nurses' primary concern is focused on the use of high intensity lights. The large amount of heat that these lights generate poses a problem. Their weight makes them difficult to adjust for focussing onto the operative field.

(b) Windowless Rooms

There are areas where rooms without windows are necessary or acceptable - e.g. operating rooms. The design at the top of the advance registration program which most of you received, provides a very good example of the problems which can be encountered in windowless rooms. The contrast in the potential quality of light received by the patient in the bed which is lit by the window, and the patient who is dependent on the ceiling fixture for light, provides a focus for our attention to windowless rooms.

We have found that patients who are confined to bed in a windowless room become depressed and bored with the monotony of seeing the same picture on the wall. Their only diversion is the activity of the medical personnel and their family visitors. Whenever possible, we transfer the patient to a stretcher and move her into a hall with windows for a short period of time; perhaps for lunch or just a cup of tea. These patients appreciate this break, even if it is just to watch the activity in the parking lot below.

Recovery room nurses working in a windowless area completely lit with fluorescent lights, complain that even the staff looks pale. This is important in an area where patients are closely watched for colour changes. The staff also complained of headaches. Nurses who had experienced different work situations, report that a room with natural light from windows, augmented by artificial light, was a much more satisfactory arrangement.

Nurses who are working in windowless offices, completely lit with fluorescent lights, complain of the eye irritation they get from this arrangement.

(c) Planning of the Night Light in Patient Rooms

The inappropriate planning of the night light has caused problems. Recently a patient whose condition required a darkened room, was being cared for in a room with lighting limited to a night light. This light, situated over the patient's bed, was really insufficient for the performance of nursing duties. In spite of the dimness of the light, it shone directly on her face. This disturbed her so much that she used a pillow to protect her eyes from the light. When we brought in a portable goose neck lamp with a hundred (100) watt bulb, directing the light to the floor as far away from the patient as possible, she was more comfortable and we had sufficient light to perform our nursing functions.

(d) Placement of Electrical Outlets and Switches

As nurses, we would appreciate if more thought were given to the placement of light switches. In rooms where patients are admitted through one door and the nursing staff use another door on the opposite side of the room, the patient is left standing in a darkened room while the nurse crosses the room to turn on the light. This provides an unsatisfactory welcome for the patient. In illustration one, we have three switches, a switch for the fluorescent light in the ceiling, a switch for the light over the patient's bed and a switch for a small night light. This night light may - or may not go on because it may have been turned off with the switch on the other side of the room. Then again, someone may have turned it off by the switch directly over the light itself. The patient's over bed light is controlled by a cord for the patient's convenience.

In the trauma rooms, the switches controlling the level of lighting in each room are located on the wall at the foot of the patient's bed - or stretcher. This means that the nurse has to leave the patient to lower the level of lighting. I will have more to say about this in my section on recommendations.

The electrical outlets are most convenient at a working level, on the wall beside the head board. In some of our labour rooms*, all of the electrical outlets were moved to the wall at the head of the patient's bed. These are convenient for equipment such as monitors, intravenous medication pumps etc. These outlets were originally placed near the floor behind the head of the patient's bed. They were difficult to use and were damaged when the beds were moved to transfer patients to stretchers.

There should be additional outlets on the wall at the foot of the patient's bed. We find that often we need an outlet to plug in a incubator or an auxiliary light for direct lighting. The cords for these extras have to be run across the room to the outlets provided at the head of the patient's bed under present conditions. This is not only inconvenient, but also a potential hazard to people having to avoid tripping over the electrical cords.

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*12' x 14'

The placement of wall switches in delivery rooms is of prime importance. In delivery rooms where the staff and patient both enter from the same door, this is not a problem because the switches are always on the wall just inside the door. The problem arises when the delivery room is planned with two doors, one from a peripheral corridor through which the patient enters and the other directly from a sterile corridor through which the staff enters. The switches are on the wall by the door leading from the sterile corridor.

In obstetrics, when a patient goes into the delivery room, she is always with the nurse. They enter through the door from the peripheral corridor. The room is in darkness except perhaps for a light coming through a window at the scrub sink alcove off the sterile corridor. The nurse has to leave the patient to cross the room to turn on the light. Even if it's only for a minute, the patient can become insecure at a time when she needs the support of the nurse. This situation could be improved by installing switches on both walls.

Recommendations

1. Natural light whenever and wherever possible. At least one window or skylight exposure should be considered where patients spend more than three hours at a time and where staff must work for a full shift.

2. Colour rendering must receive careful attention in critical areas such as nurseries, recovery rooms, intensive care units and trauma treatment areas. Treatment decisions may be altered by inappropriate lighting.

3. Flexible task lighting where required. In the emergency room for instance, an adjustable light with an incadescent bulb at the head of the stretcher may be required to serve when the general lighting is too bright for the patient.

4. The interaction of lighting and room colour should be considered, especially in windowless rooms. The glare of fluorescent lights on near white walls should be avoided. This may be one way to reduce the headaches experienced by staff.

5. In areas where whole shifts are spent by staff at night, "day light" bulbs on their equivalent may be needed to avoid complaints of headaches.

6. Movement patterns in special areas such as labour and delivery rooms must be considered in locating switches and electrical outlets.

7. In special areas such as the holding area for operating rooms, the special requirements of patients and staff must be considered. Enough light for the staff; but, not so strong as to disturb the patients.

8. Pay special attention to lounge and dining areas. Comfort and relaxation are important to meet the objectives of these areas.

EXPERIENCE REPORTS -
"ASTHETICS IN HOSPITAL LIGHTING"

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Our philosophy along with our clients requirements has been to create functional, yet asthetic, lighting in health care facilities.

It is our responsibility to provide good quality lighting so that highly technical tasks can be performed while providing a home away from home for patients (i.e. patients in a general Hospital, expectant mothers and critically ill children etc.) who have to use these spaces during what could be a traumatic experience for the average person.

This experience report deals with how such a philosophy has been translated into working experience in four recently commissioned Hospitals in the Vancouver area. They consist of an Acute Care Hospital (Lions Gate Hospital, an Emergency Centre for the Greater Vancouver area, Vancouver General Hospital) and two tertiary care hospitals (Childrens Hospital and the Grace Maternity Hospital)

Starting with the non-critical patient areas we look at Slide 1 a bed head unit and overhead incandescent light in an emergency ward.

Slide 2 shows a Critical Patient Area Emergency Centre at V.G.H. - lighting in the Trauma area, where all critical functions including minor surgery are performed.

Slide 3 shows an Intensive Care Unit in a general hospital. Principle used here is the overbed (or bedhead light) with up and down lights. The examination light sources are incandescent one at the upper end of the bed and the other at the lower end of the bed.

Slides 4 & 5 show the Cardiac Monitoring Unit at V.G.H. Because of the constant surveillance required by nursing staff there is great deal of glazing in this unit. The lighting had to respond to glare conditions. We have used low glare Parabolic Reflector type fixture to overcome this. This principle will be highlighted again when we look at Nurses Stations.

Slide 6 shows that another critical patient area, at Childrens Hospital, is the EEG rooms. These use low level incandescent lighting, controlled by ind. switches.

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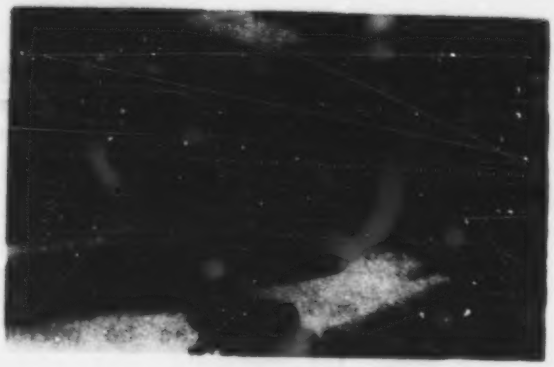

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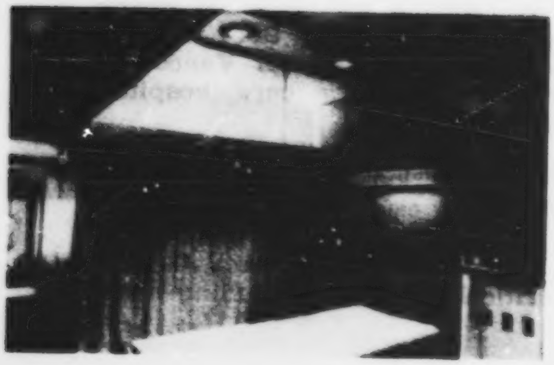

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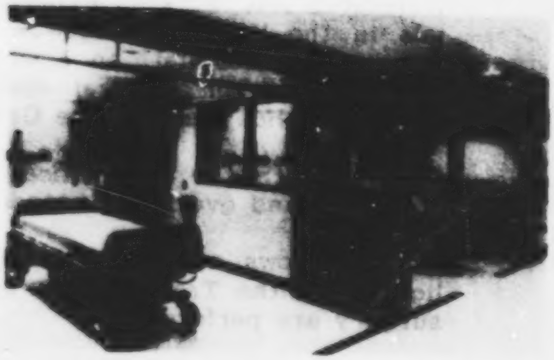

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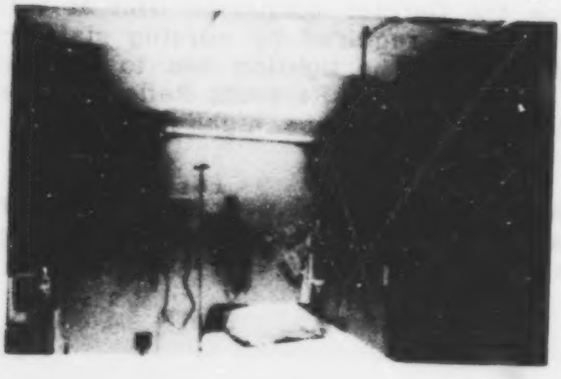

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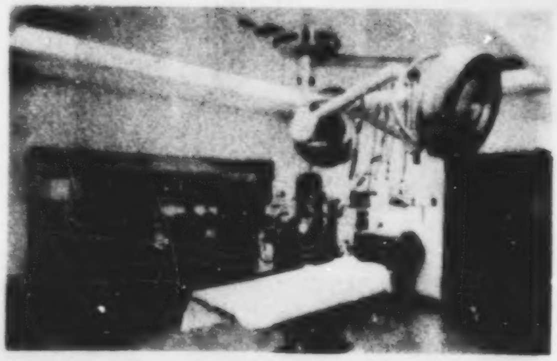

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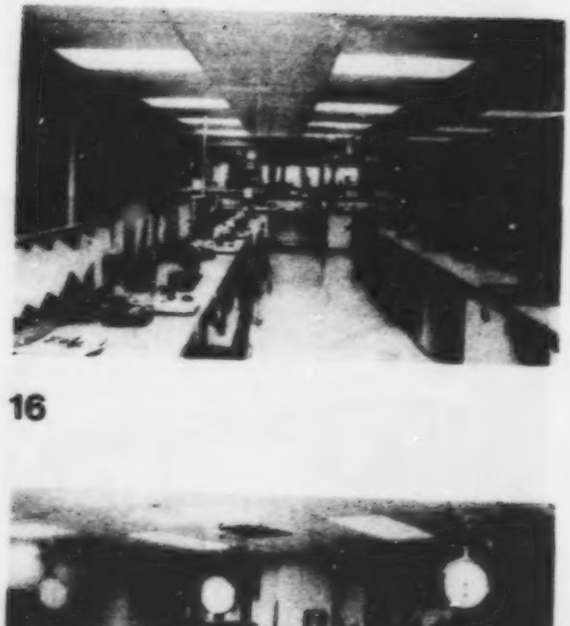

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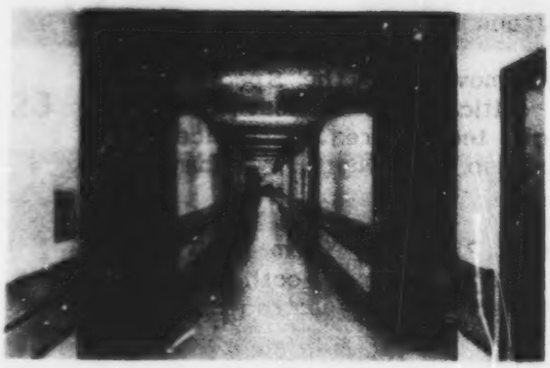

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Slides 7, 8 & 9 show that operating rooms have to provide extremely good general lighting as well as the point source required at the table. Here we have shown 3 different O/Rs in an acute care or general Hospital, and special O/Rs at Childrens Hospital. All lamps used in these O/Rs are colour corrected.

Slide 10 shows the recovery room at Childrens Hospital.

As indicated in Slides 11 & 12, we now move into the Special Care Nursery at the Childrens Hospital, for critically ill babies. From a services point of view this is a high tech. area. Notice the positioning of lights over basinets. Also multilevel switching is provided at the wall console.

Slides 13, 14 & 15 show the lighting in a Radiology room at V.G.H. and the lighting in a Radiology room at V.G.H. control booth for C.T. Scanner room at Childrens where low level lighting is required for computerized equipment.

Slides 16 & 17 show that in a laboratory generally good quality lighting is required throughout the lab. Acute Care Lab. at Lions Gate Hospital. Lab. at Childrens/Grace Hospital.

Slide 18 shows the Morgue at an Acute Care Hospital. Again we have used color temp. corrected lamps.

Slides 19, 20, 21 & 22 show that circulation spaces provided in Hospital are used for a multiple of functions. Moving of patients in stretchers is a key factor in determining good lighting. Here we show examples of a number of different ways in which we have responded to this requirement.

(a) Regular type corridor lighting at Childrens Hospital
(b) Regular type corridor lighting at V.G.H.
(c) Offset type corridor lighting using Parabolic reflector fixtures at Lions Gate Hospital
(d) Indirect corridor in the I.C.U. at Lions Gate Hospital.

Slide 23 demonstrates the challenge presented to us during the design of the Grace Maternity Hospital was to come up with a design of a room where labour and delivery were to take place in the same room. We have tried to combine the ambience of home lighting with the high tech. operating room type of lighting. The high risk labour delivery suite at Grace Hospital.

With Slides 24, 25, 26 & 27 we move from patient care areas into Utility areas e.g. equipment rooms. Here the function is to read a meter, a label and have adequate lighting for maintenance purposes.

(a) Main Electrical Room at V.G.H.
(b) Boiler Room at Lions Gate Hospital

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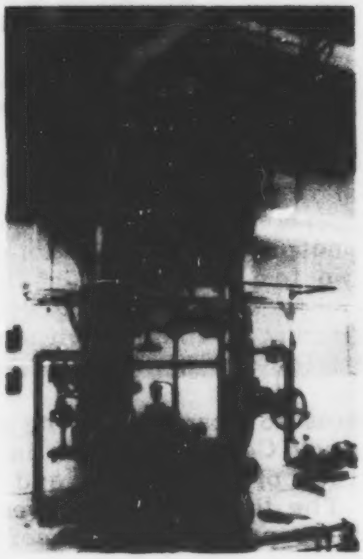

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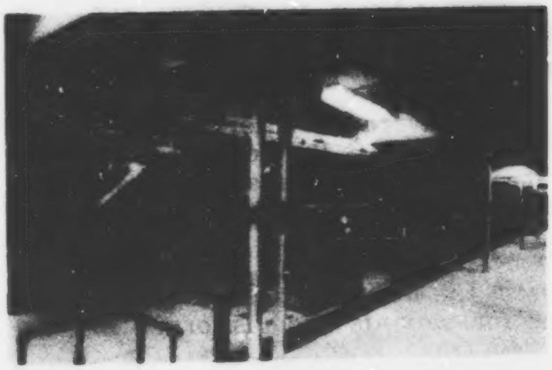

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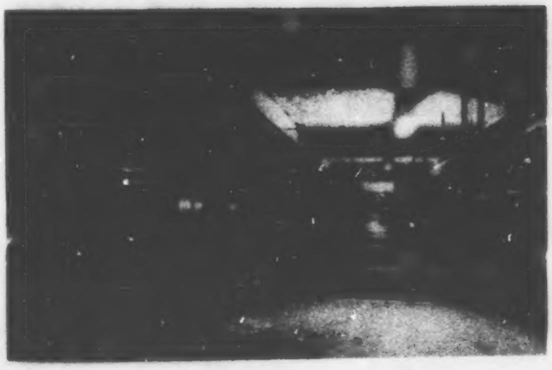

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(c) Sub Equipment Room - Fire pump at V.G.H.
(d) Interstitial floor lighting at V.G.H.

Another utility type function is parking, as seen in Slides 28 & 29.

(a) Parking at L.G.H.
(b) Parking at Childrens

As seen in Slides 30, 31, 32 & 33, nursing stations always present a variety of lighting tasks, ranging from general, to charting to reading V.D.T.s.

(a) Nurses Station in Childrens
(b) Nurses Station in C.M.U., V.G.H. (using the Parabolic reflector type)
(c) Nurses Station in C.M.U., V.G.H. (fixtures for low glare)
(d) Nurses Station in Quiet Rooms at the Pschy. Area, V.G.H.

As seen in Slides 34 & 35, waiting areas must make an impression on the visitor yet put him at ease.

(a) Kids waiting area at Childrens/Grace
(b) Teenage waiting area at Childrens/Grace.

Since hospital staff is generally working under well illuminated conditions we feel that there should be a change of pace when they have to relax. A staff cafeteria with a mixture of indirect fluorescent and incandescent downlights with multilevel switching provides this relief for the staff day or night. As seen in slide 36.

Entrances to hospital can be confusing to the average visitor. At the Emergency Centre, as seen in Slides 37, 38 & 39 V.G.H. we have used a mixture of fluorescent and HPS fixture to create a sense of direction. The fluorescent fixtures guide one into the Triage while the HPS downlights provide good general lighting.

Main lobbies - we have tried to deviate from the dominating clinical type atmosphere and create a welcome ambience for patients and visitors.

(a) Entrance Lobby at Childrens Hospital
(b) Upper Lobby at Lions Gate
(c) Main Lobby at Lions Gate

As seen in Slides 40, 41 & 42 respectfully.

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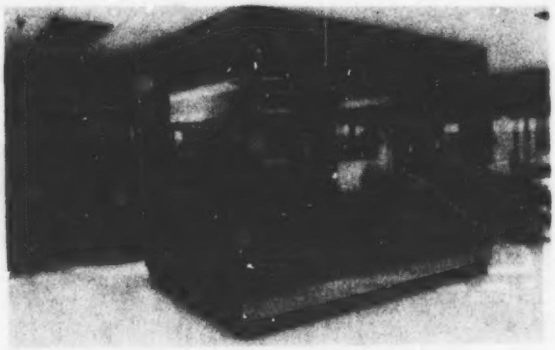

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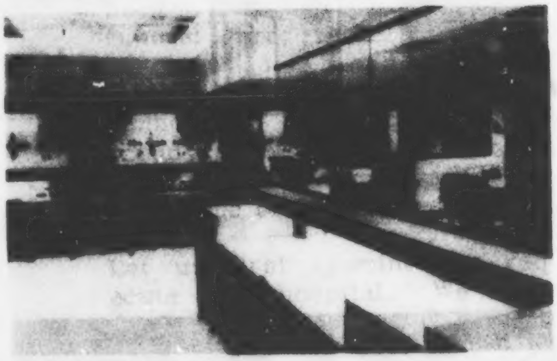

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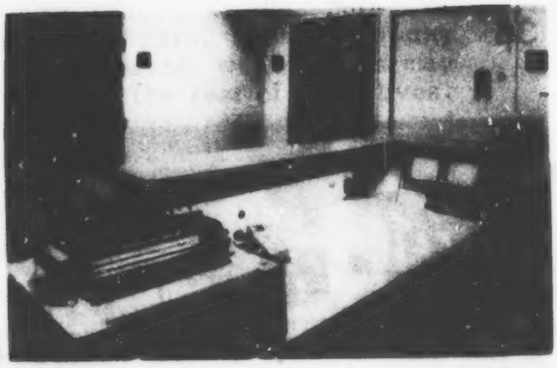

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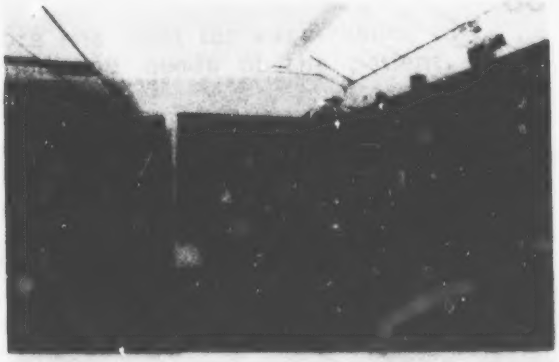

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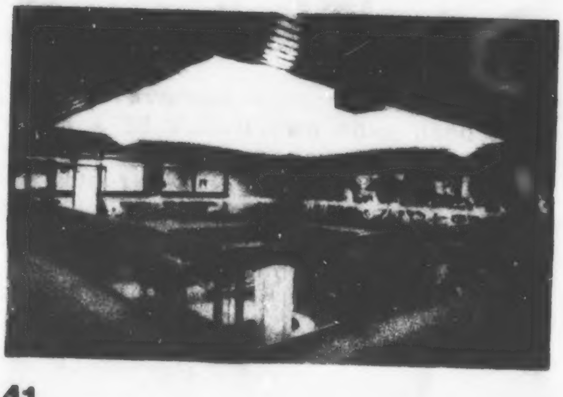

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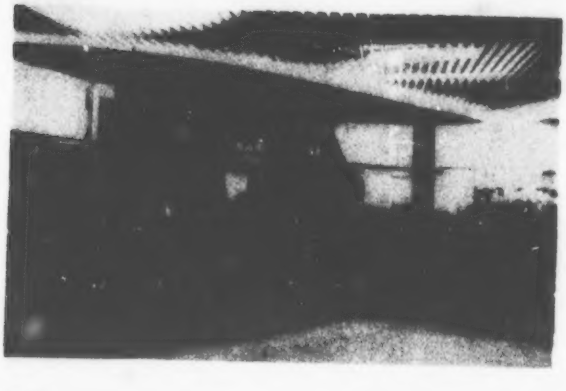

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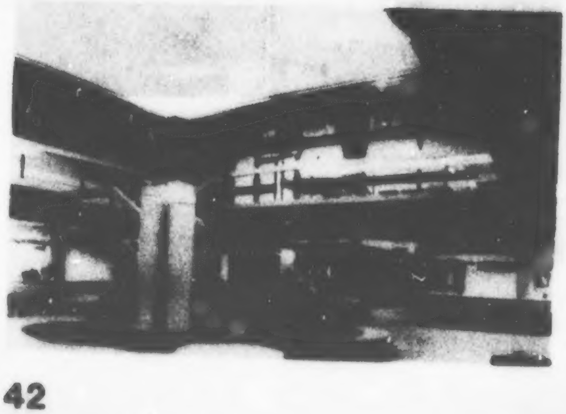

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EXPERIENCE REPORTS -
"PATIENT ORIENTED LIGHTING"

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Synopsis

Patient oriented lighting is generally recognized as overbed lighting for bedridden adult patients. However, patients vary in age from pediatrics to geriatrics; some are confined to beds or wheelchairs, while others are completely ambulatory; their mental condition varies from normal to severe depression; and they may require cardiac care or minimal care; their stay may vary from a few hours, such as in day surgery, to a few days for elective surgery patients, while others may have to be confined to a health care facility for the rest of their lives. Each category of patients has different lighting requirements and occupy many different areas during their stay in a health care facility. Lighting must respond to their specific needs. This discussion will deal with some of these needs and examine some solutions.

Let us first examine the requirements of a bedridden patient in an acute care hospital. We know that most bed locations will have some daylight as windows have long been recognized as an essential element for a person's orientation and mental well being. Lighting nevertheless plays an important part in the patient's environmental space. Addressing ourself to a general care ward we should examine the requirements.

The prime requirements are general lighting, for reading and TV watching, which today occupies a large portion of the patient's time.

Light for examination of patient by doctors and light for surveillance to help the nurse to determine the condition and needs of the patient. The light in the patient's sphere must be of a good colour to determine abnormality in patient's appearance, and the illuminance must be sufficient for the patient to read by, for the doctor and nurse to examine by and yet it must be of a quality that is unobstrusive to the patient himself and to his neighbour lying in the next bed. The problem of glare from beds on opposite wall has been greatly reduced in the past few years with the reduction of public or multi bed wards. Today most rooms contain one or two beds and the two beds are generally located side by side, although some designers have found that there may be a space and circulation advantage by placing beds on opposite walls of a two bed room.

In general care bed rooms, the lighting requirements have been met by some of the following elements singularly or in combination of two or three elements. The most common is the wall mounted bed light, usually fluorescent; an adjustable examination light, usually incandescent, this light can be permanently mounted on the wall or be part of the bedlight or it could be a portable one which can be inserted in the IV rod holder on the bed; ceiling mounted examination lights, either fluorescent or incandescent (Quartz) located above the bed and ceiling mounted general light which again can be fluorescent or incandescent.

The overbed wall mounted fixture usually has one or two lamps that provide the upward or indirect component of illumination. This component in a single bed room provides 50 to 100 lux of general illuminance and is very much appreciated by the patient and his guests, as it gives a soft unobstrusive and diffused light. The downward component will provide the illuminance required for reading and examination. Generally, the downward component is well shielded and the distribution is concentrated directly below the fixture which provides an illuminance at the head of the bed of 450 to 300 lux as illustrated in transparency figure 1.

The values shown are for comparison only and are not necessarily representative as the age of the lamps, the type or maintenance schedule is unknown. In this figure it can be seen how the light level falls off from 450 lux to 150 lux with 1 meter. However, it is very difficult for a patient to lie in a prone position for very long, so we incline the head of the bed 250 mm and the illuminance on the pillow increases to 500 lux as seen in figure 2.

That appears to be an improvement but what happens when we add a patient to the bed? We find that the normal reading material moved to approximately 1 meter from the wall as seen in figure 3. The resultant level is 250 lux. This is an adequate illuminance for a person below the age of 45 without any sight disability. Lifting the fixture to approximately 1.8 meters above the floor improves the illuminance marginally. As we incline the bed further, this situation gets worse as we can see in Figure 4.

In preparation for this paper, I approached Murray Springthorpe, of the Scarborough General Hospital, for permission to take some measurements and pictures of the overbed fixture to illustrate the above conditions.

"Isn't it strange" he said "I have discovered this problem many years ago and have been working on the design of a bed light fixture for some time". He took me to his office and pulled out a 100 mm thick file of correspondence with patent attorneys, drawings, sketches and many paid bills. What a coincidence. He immediately arranged a rig with an identical fixture and a bed to take measurements.

Figure 5 shows the illuminance readings. By moving the fixture out 330 mm from the wall the illuminance on the task increased from 250 to 500 lux and in the higher incline as shown in figure 6 the illuminance increased from 200 lux (figure 4) to 420 lux. In both cases moving the fixture away from the wall resulted in a marked improvement.

The fixture could be adjustable so that the distance from the wall could vary from zero to 400 mm. I hope Murray continues to work on this project, and who knows, some time in the future we may all be specifying "Springthorpe" fixtures.

The following slides will illustrate the above.

Slide 1 shows the mock up with the bed in the flat position. In this position the fixture at the wall is mounted at 1.5 meters above the floor. Slide 2, shows the bed in half raised position and slide 3 shows it in the fully up or almost sitting position. Slide 4 shows the light at the wall and only one lamp on Slide 5 shows the light moved out from the wall some 330 mm and both lamps on.

The next few slides will show an attempt to overcome problems of fixture location. This hospital wing is for extended care. In this case, the fixtures are mounted in a valance above the bed with an acrylic shield below. Light is switched at the door and at bed. The lights located at the head of the bed give general illumination and light for reading instead of in the center of the room where the patient would be looking at the light. A Luxo wall light is provided for close work in the bed or in the chair and for examination purposes. Slide 6 shows a two bed ward with ceiling lights and Luxo reading/exam lights. It may be of interest that the Z32.2 Code - "Use of Electricity in Patient Care Areas", Article 5.6.2 does not allow the use of the Luxo type fixtures unless they comply with CSA C22.2 125 electromedical equipment. Thus, in provinces which adapt that Code, this light will not be permitted to be used. In Ontario, the next issue of the Electric Safety Code adopted many measures from the Z32.2 Code, but left the restriction of Luxo light out.

This type of lighting arrangement has another very important feature in that the IV rod, which is usually attached to one corner of the headboard, does not interfere with the lighting fixture when the bed is raised.

Slide 7 shows the night light in the maximum brightness. The light is switched at the door and dimmed at the bed.

Today general hospitals provide a wide range of services, some of which a few years ago were provided in special institutions and sanitariums. These include cardiac care, psychiatric care, pediatric care, geriratrics and so on.

The next few slides will attempt to show the varied requirements and how some of these requirements were met.

Here are a few slides showing different solutions to the critical care and cardiac care units. Slide 8, shows how congested the bed wall can get and one must resort to ceiling mounted lights with a wall mounted exam light as seen in Slide 9.

The next Slide 10 shows critical care unit with overbed light and two ceiling mounted overbed adjustable exam lights. The exam lights are dimmer controlled.

Slides 11, and 12 show a room in a psychiatric ward where an attempt has been made to deinstitutionalize the room by the use of hotel type furniture and lighting. It is hoped that this type of environment is less stressful to the patient than the standard general care ward would be.

Similarly, Slides 13 and 14 show a bedroom in the Bloorview Children's Hospital where children may have to spend many years. Here the room looks more like a typical teenagers room; although this one is especially tidy.

In this hospital, the patients spend relatively little time in their rooms so other areas have been treated as patient "Living space" areas. This corridor as seen in Slide 15, for example, which is typical of all bedroom corridors, is treated more as a room than a corridor with wall washers for display areas and valance lighting for interest and contrast.

Another area of interest is shown in Slide 16, a playroom, where high illuminance of approximately 1000 lux has been provided.

Slide 17 shows the transition corridor between the hospital/residential wing and the school wing. This corridor serves as a "street" with trees and street lights to emphasize the separation between the hospital (residence) and the school wing.

Slide 18 shows a typical classroom. A number of students at this institution have sight problems and 1500 lux illuminance has been provided. The same principle has been extended to the library space, Slide 19. This shows day lighting from a series of skylights and Slide 20 shows the combined effect of day lighting and fluorescent.

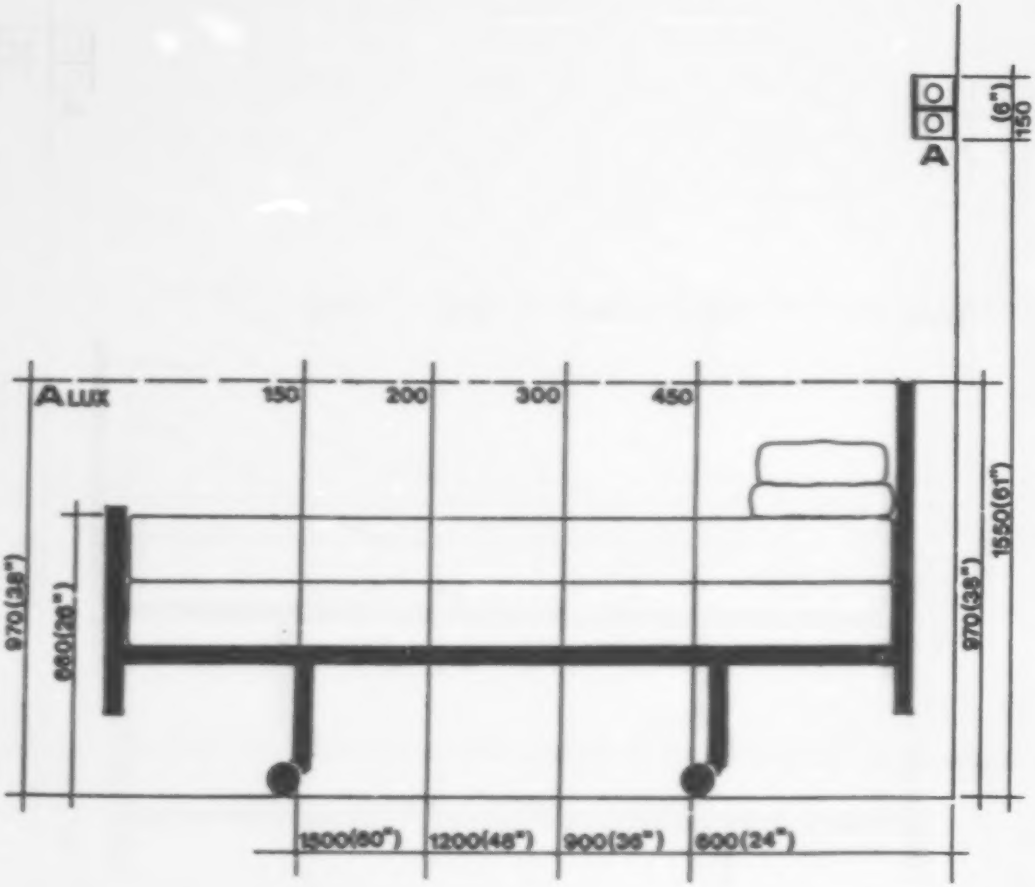
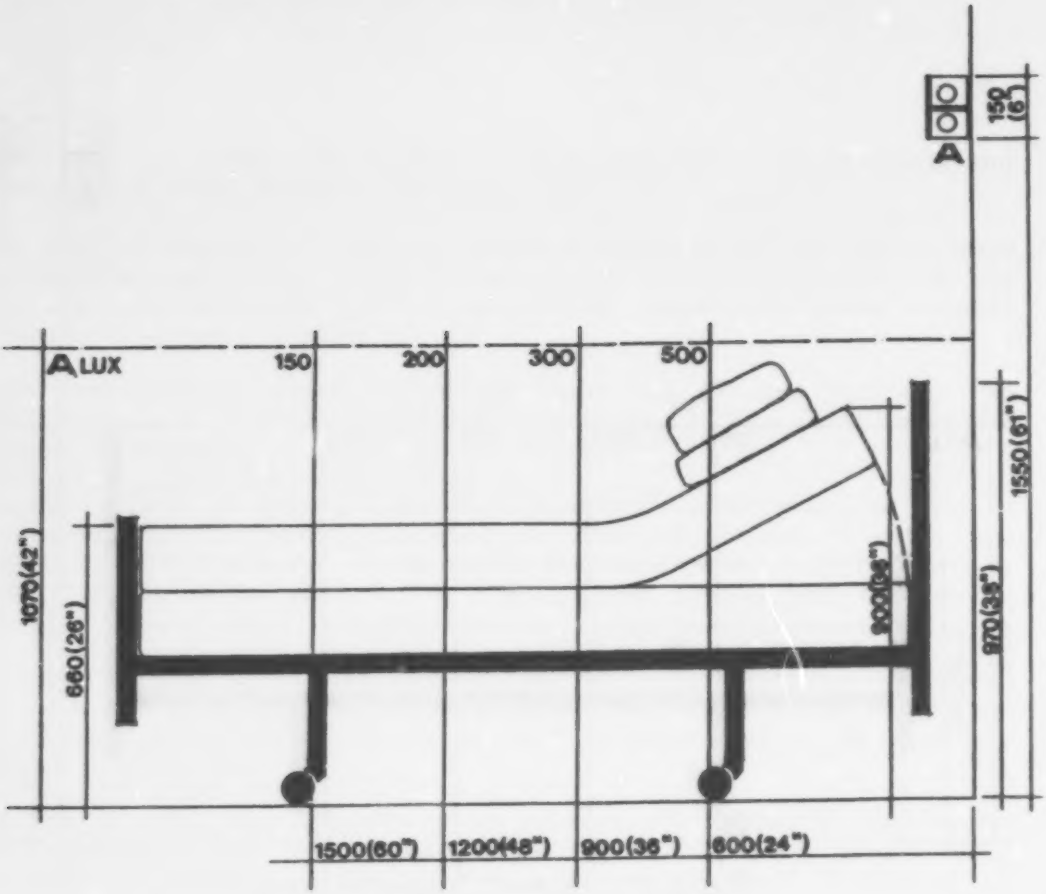

A
150
(6")
A LUX
150
200
300
450
970(38")
680(27")
970(38")
1550(61")
1500(60")
1200(48")
900(36")
600(24")

Fig. 1. CONCENTRATION OF 300-450 LUX AT HEAD OF BED


150
(6")
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150
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1070(42")
660(26")
900(36")
1550(61")
970(38")
1500(60")
1200(48")
900(36")
600(24")

Fig. 2. INCREASE IN LUX TO 500 WITH ADJUSTMENT OF BED

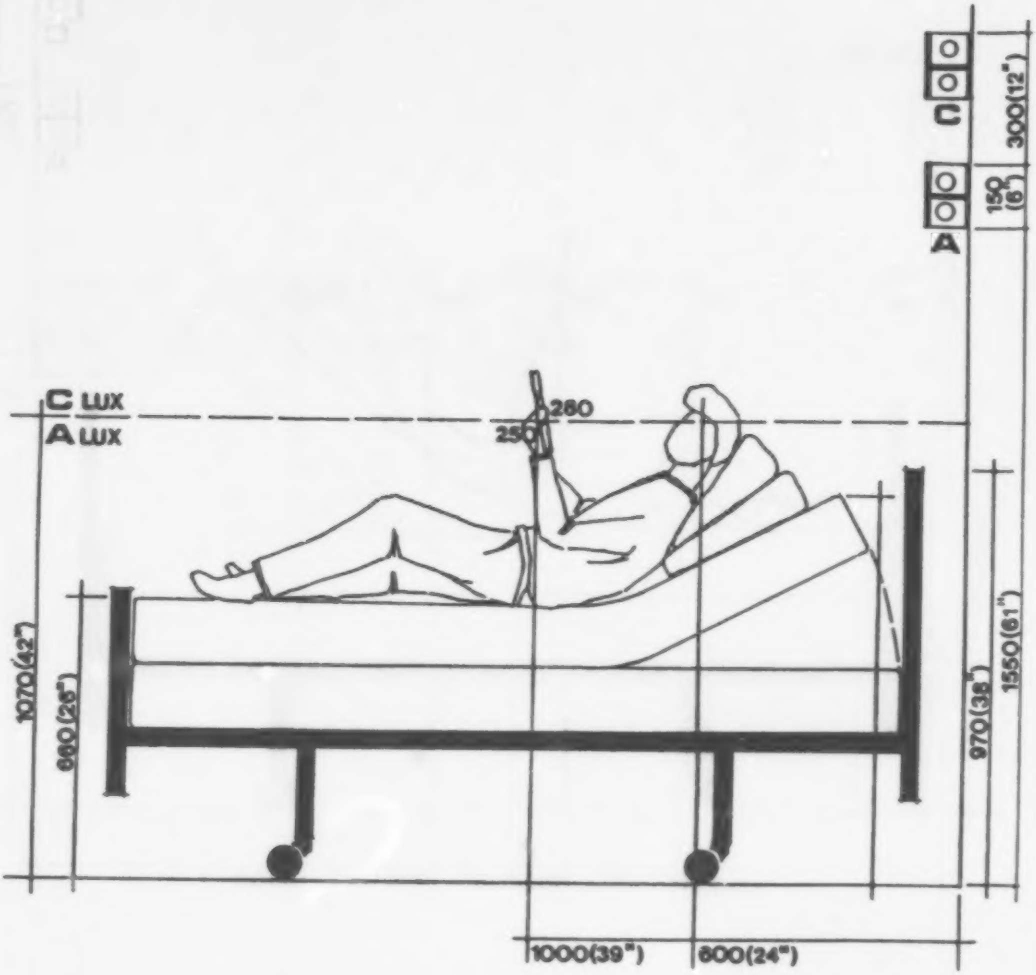
C LUX
A LUX
280
250
1070(42")
660(26")
970(38")
1550(61")
1000(39")
600(24")
A
150 (6")
C
300(12")

Fig. 3. READING MATERIAL HELD AT APPROXIMATELY 1 METER FROM WALL

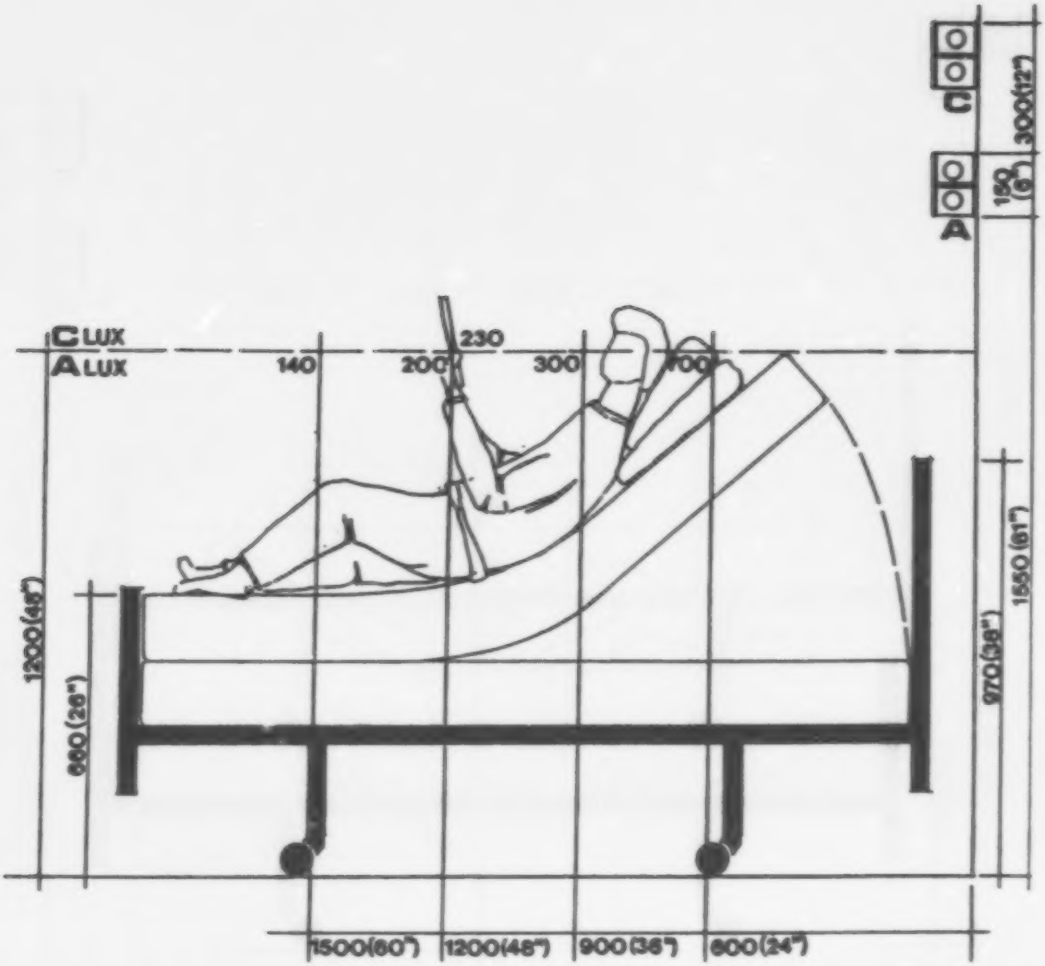
C LUX
A LUX
140
200
230
300
400
C
A
150 (6")
300(12")
1200(48")
660(26")
970(38")
1550(61")
1500(60")
1200(48")
900(36")
600(24")

Fig. 4. FIXTURE AT 1.8 METERS, WITH FURTHER ADJUSTMENT TO BED

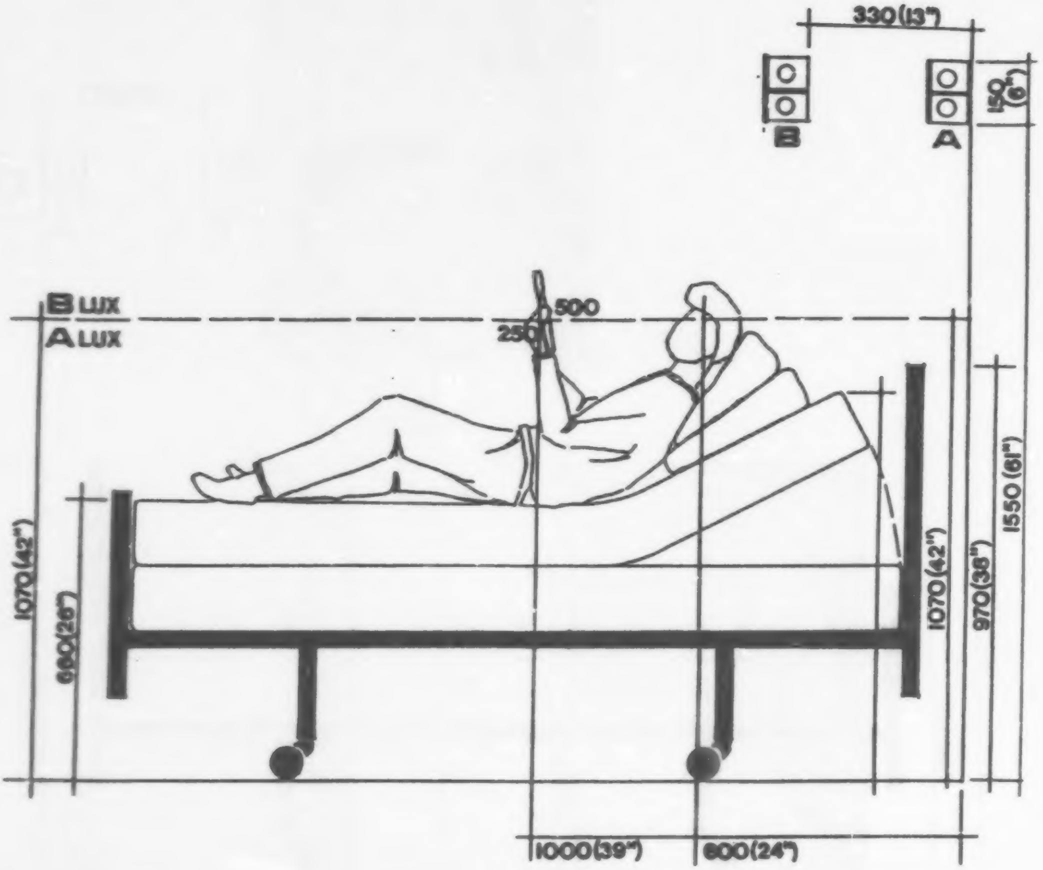
330(13")
B
A
150 (6")
B LUX
A LUX
500
250
1070(42")
660(26")
1070(42")
970(38")
1550(61")
1000(39")
600(24")

Fig. 5. THE ILLUMINANCE READINGS

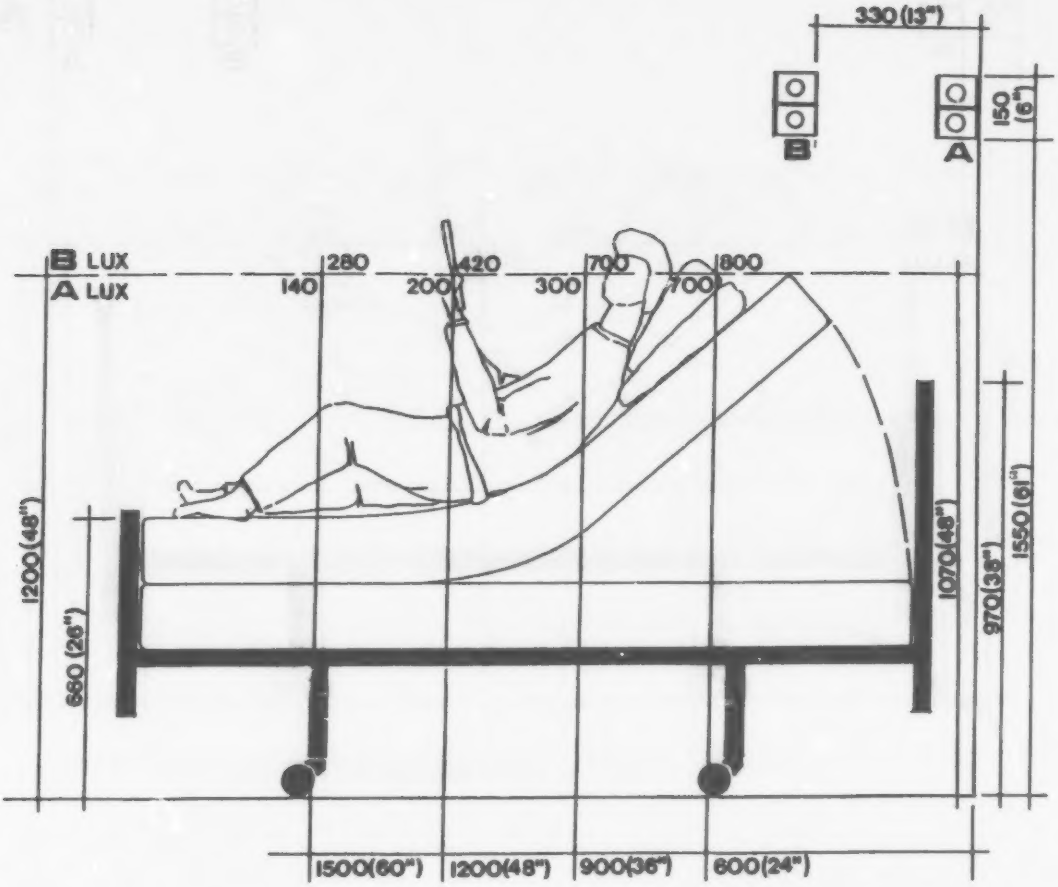
330 (13")
B
A
150 (6")
B LUX
A LUX
280
140
420
200
700
300
800
700
1200 (48")
660 (26")
1070 (48")
970 (38")
1550 (61")
1500(60")
1200(48")
900(36")
600(24")

Fig. 6. MOVING FIXTURE OUTWARD, INCREASES LUX BY 200-250

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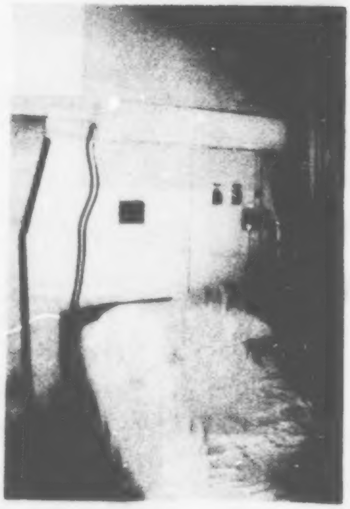

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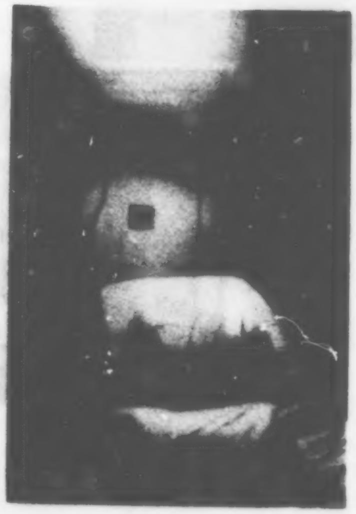

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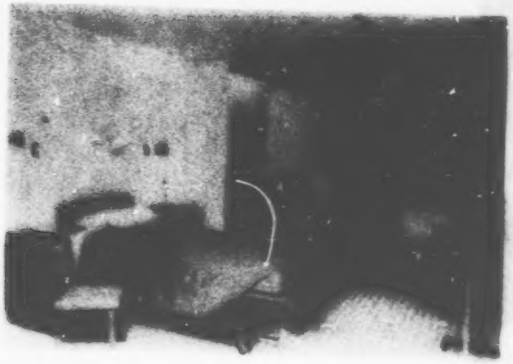

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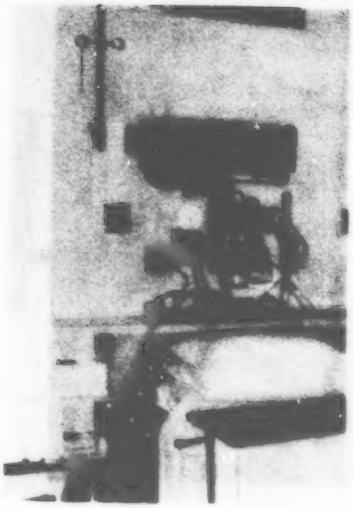

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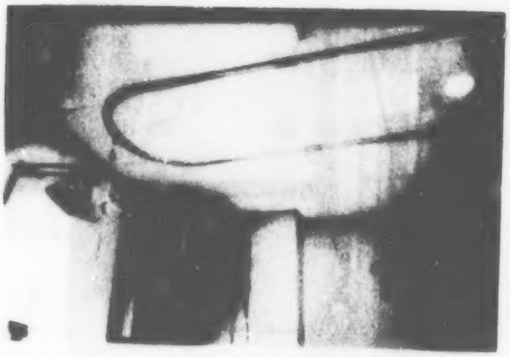

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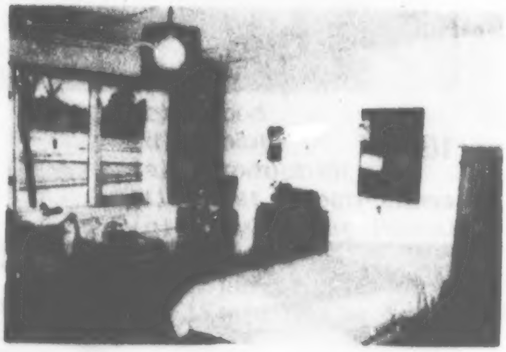

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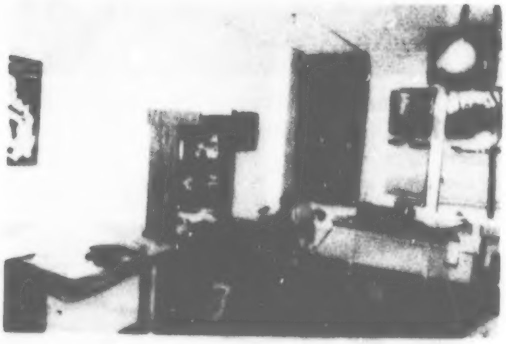

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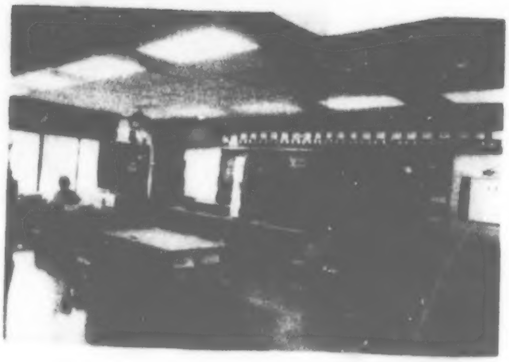

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EXPERIENCE REPORTS
"LIGHTING DESIGN"

K. Loach, P. Eng.
H. & H. Angus & Associates Ltd.
Toronto, Ontario

Introduction

It is increasingly evident that the lighting is not only an engineering discipline; it is an art of marvellous subtlety and resource.

Today, lighting as an art, combined with new kinds of energy light sources, luminaires and techniques, has brought a more subtle enhancement to the illumination of hospitals and in fact, to every kind of space used by people.

Criteria for Lighting Design:

(a) Activity needs for visual information:

- Is it light for critical seeing?
- Is it light for decoration?
- Is it lighting for machines?
- How severe is the seeing task?
- What are the architectural and decorative requirements/-construction limitations?

(b) Clarity
(c) Mood
(d) Colour
(e) Productivity
(f) Cost Effectiveness
(g) Daylighting Potential
(h) Readily Maintainable
(i) Energy Effective
(j) State of the Art Alternatives

Hospital Lighting Design Considerations:

Visual tasks to be performed

(a) The importance and delicacy of the particular task from the standpoint of time and accuracy required without undue fatigue.
(b) Upon the person performing the task.
(c) Upon the task itself.

Example: Where task levels are high, as in surgery, there should be three zones of lighting

(a) highest in the operative field
(b) lower level of surrounding the table
(c) a peripheral one grazing the wall

Desired Appearance of the Space

Energy Restraints

(a) Ontario Ministry of Health recommends 22 watts/metre^2
(b) Experience indicates that the 22 watts/metre^2 can even be further reduced to between 15 watts/metre^2 and 17 watts/metre^2 by simply providing task lighting using, energy efficient light sources, and energy efficient double life cool coil ballasts.

Design Recommendations on Reducing Energy

Use only efficient light sources in a design

(a) fluorescent
(b) (4'-0" and 3'-0" lamps only)
(c) high intensity discharge lamps:
mercury
metal halide
high pressure sodium (only if earth tone colours are used)

Retrofitting

Reduced wattage fluorescent lamps of the 70% and 50%, output type should be considered.

Reflectances of Surfaces

80% - 90% for ceilings
50% - 60% for walls
20% - 40% for floors
25% - 45% for furniture and equipment (matte)

Luminaires should be selected based on their efficiency, photometric distribution, maintainability and cost, i.e.: 12" wide two lamp fluorescent luminaire is only 63% efficient. 20" wide two lamp fluorescent luminaire is 73% efficient.

Provide energy efficient double life cool coil ballasts.

Luminaire	Standard Fluorescent Ballasts	Energy Saving - Fluorescent Ballasts
Single Lamp	48	41
Two Lamp	90	82
Three Lamp	142*	126*

*Two Ballasts/Luminaire

Provide local switching throughout all rooms

Switching should provide three levels of illumination if at all possible (i.e. three lamp fluorescent luminaire)

Daylighting System

Economic Restraints

Lighting Design Concepts

Waiting Area, See Slide 1

(a) General Lighting Design
(b) Reflectances:
    Ceiling - open concept with dropped vertical baffles
    Wall - eggshell
    Floor - light brown carpet

Level of illumination 220 Lux maintained

Source:

(a) Colour corrected mercury - 3000 K
(b) Encapsulated ballast

Lamp Life 24,000 hours

Luminaire:

(a) suspended enclosed cylinder

Emergency:

(a) secondary tap off the ballast

Atrium Lighting, see Slide 2 and 3.

General Lighting Design/Task

Reflectances:
Ceiling - glass 10%
Walls - eggshell
Floor - wood finish

Level of illumination 220 Lux maintained

Source:

(a) colour correct mercury - 3000 K
(b) encapsulated ballast

Lamp Life 24,000 hours

Luminaires are located directly over the stairs (reflected light)

Emergency:

(a) secondary tap off the ballast

During the day luminaires are turned off to save on energy and take advantage of natural daylight.

Waiting Area, See Slide 4.

General Lighting/Accent Lighting

Reflectances:
Ceiling - open concept with dropped vertical baffles
Wall - eggshell
Floor - light brown carpet

Level of illumination 220 Lux maintained with pockets of illumination through the skylights providing a higher level of illumination.

Design Concern - simulating this in the evening.

Luminaire - Bare Lamp

Sources:

(a) colour corrected mercury - 3000 K
(b) remote mounted
(c) incandescent - provides 3:1 ratio

Waiting Area, See Slide 5.

General Lighting Design

1

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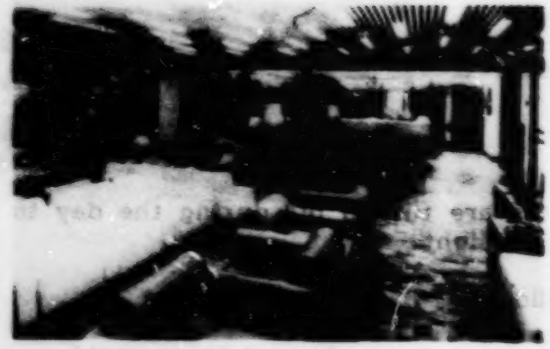

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Reflectances:
Ceiling - metal linear ceiling
Wall - dark/wood
Floor - dark wood

Source:

(a) Fluorescent - warm white

Opal lens - excellent in appearance
- poor in efficiency

Level of illumination 220 Lux

Alternatives - H.I.D.

Main Entrance (Toronto General Hospital), See Slides 6 & 7.

General Lighting/Accent Lighting

Reflectances - fairly good

Level of illumination 220 Lux maintained

Sources:

(a) colour corrected mercury (3000 K)
(b) fluorescent (warm white)
(c) track mounted low voltage incandescent/fluorescent combination (longer lamp life)

Luminaires:

(a) recessed mercury luminaires
(b) special luminaire built for the main lobby

Emergency:

(a) fluorescent
(b) H.I.D.

Energy:

(a) luminaires are turned off during the day to take advantage of natural daylight

Cafeteria, See Slide 8.

Task lighting - putting light where it is required

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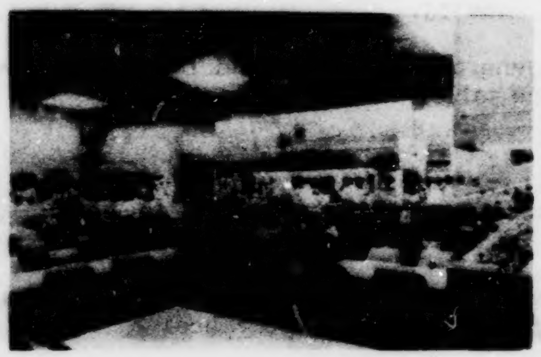

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Enhances the space where one has to eat

Source:

(a) fluorescent - (warm white)

Luminaires:

(a) recessed fluorescent

Reflectances - not ideal

Nurses Stations/Out Patient, See slides 9, 10, 11, 12.

General Illumination/Task Lighting

Reflectances are usually excellent

Level of illumination 320 Lux maintained with 750 Lux on the task.

(a) fluorescent lighting in the ceiling provides general illumination
(b) fluorescent lighting beneath the counter provides for task lighting. Luminaires should not be within the patient's direct view.
(c) use only 4'-0" and 3'-0" luminaires when mounting fluorescents under cabinets
(d) corridors adjacent should have transition lighting - a higher level during the day and switched at night
(e) emergency:
Luminaires at the Nurses' Station should be on emergency.

Emergency Treatment, see slide 13.

For emergency treatment general lighting should be provided with supplementary lighting over the table.

ICU, see slide 14.

Lighting in this case should enable the observer to note every small detail. Luminaires should be switched at the bed.

Lighting should be avoided with a predominance of any colour which may give the patients complexion a false appearance.

Colour improved lamps should be considered.

General lighting should be capable of dimming with luminaires located to avoid glare.

Standard #12 acrylic lenses have been used in this design.

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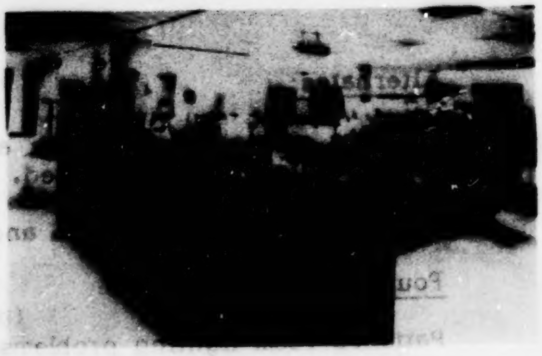

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Alternates:

Possibly use parabolics with acrylic base (½" x ½" x ½"). Excellent when monitors are being used.

Bedwards, see slides 15, 16 and 17.

Four Basic Concerns

Patient's room lighting problems are to reconcile the need for lighting at various times by various people and usually to provide such lighting as simply and economically as possible.

i.e. patient
nurse
doctor
housekeeping personnel

Bedlight Design Criteria

(a) removable plug-in electric tray comprised of ballast, lampholders and wiring
(b) hinged exterior enclosure
(c) acrylic lenses top and bottom
(d) electric tray and the exterior enclosure should be removable without tools
(e) tray and enclosure should have no loose screws or loose
(f) hardware
the luminaire should be well constructed

In other words, total flexibility

Design

Wall mounted fluorescent bed lights with upward and downward component

(a) two fluorescent lamps indirect
(b) one fluorescent lamp for reading
(c) one examination light

Switching

(a) two lamps for indirect switched at the door
(b) reading lamp switched at bed light
(c) switch on examination light

Examination light as seen in Slides 16 & 17, being used as a reading light. Not Recommended

Administration - (New Concern)

- (a) general offices
- (b) libraries
- (c) admitting
- (d) medical records
- (e) nurses stations

Lighting for Machines - (C.R.T. Lighting)

CRT screen performs as a mirror. It reflects everything that could be seen if it were replaced by a standard mirror. The superimposing of these mirror reflections on a screen, along with printing or information being transmitted from the computer, can contribute to errors and eye fatigue and poor work performance.

Possible Solutions:

- (a) Locate the CRT so that the operator will not see any bright surfaces such as windows, glossy or chrome surfaces, etc.
- (b) Provide portable partitions behind the operator. Partitions however should not have contrasting patterns.
- (c) Add filters over the CRT screen.
- (d) Luminaires should be of low brightness (footlamberts) so that they do not reflect as bright spots in the screen.

Possible Lighting Solutions

Indirect lighting (whole ceiling as one brightness)

- (a) H.I.D.
- (b) Fluorescent built into the furniture

Low brightness direct luminaires

- (a) parabolic louvres (½" x ½" x ½") i.e. possible dungeon effect
- (b) low brightness Alzak troffers

Lighting levels should be adequate for all tasks to be performed

Existing Hospitals: (Saving Energy)

Overhead on substituting lamps

New fluorescent lamps, as seen in Slide 18, that replaces the 60 watt incandescent lamps and below

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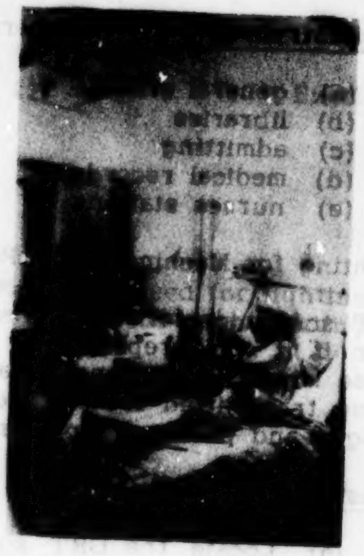

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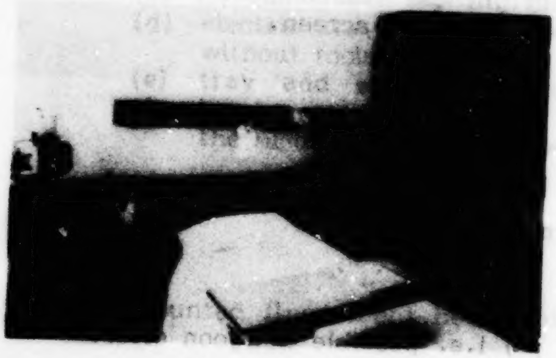

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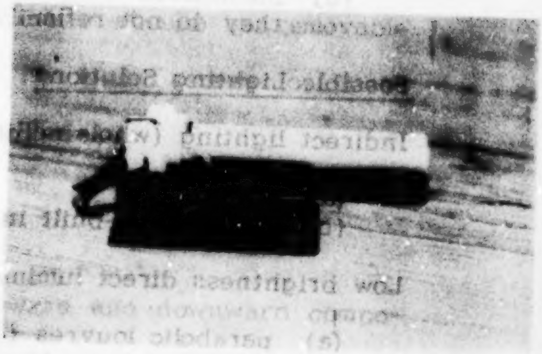

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LAMP	COLOUR RENDERING INDEX	LUMEN OUTPUT	LAMP WATTS	LAMP LIFE
PL7	82	400	7	10,000
PL9	82	600	9	10,000
PL13	82	900	13	10,000

Overhead

New Fluorescent SL 18 Lamp

Fluorescent

SL 18 120 V	Information	60 A - 120 V
Fluorescent	Technical principle	Heated filament
18 (total)	Rated wattage	60
Greater than 7,500	Average life (hours)	1,000
900	Lumen output	862
50	Efficacy (lumens per watt)	14.4
2700	Colour temperature (Kelvin)	2650
Medium	Base	Medium
Prismatic	Bulb finish	Inside frosted

Conclusion

The Lighting Consultant today in Hospital lighting has considerable latitude in the selection of lighting solutions.

Since lighting systems are designed for the human viewer, the lighting designer must constantly strive to understand what viewers really perceive, both as a function of what they see and how their intelligence and experience inform their sight.

EXPERIENCE REPORTS -
"EXAMPLES OF HOSPITAL LIGHTING"

John Chandler, B.Arch.
Partner Bregman & Hamann
Architects & Engineers

Until the mid-sixties the design of hospitals in Canada was dominated by two factors: the need to accommodate extensive ward areas for convalescent nursing care and the requirement that these ward areas be naturally ventilated.

These constraints resulted in hospitals being designed in various configurations of long narrow nursing wings. The wings rarely exceeded fifty feet in width and circulation was by means of a single central corridor. One advantage of these early plans was that sunlight and views to the outside were available to most areas of the hospital.

As there is little physical difference between the various areas of the hospital and because the choice of materials and lighting fixtures suitable for hospital use were so limited, all areas of these hospitals tended to be designed in a consistently "institutional" style. Little regard was paid to the fact that the different functions, which make up a modern hospital, would require different lighting design solutions.

Through a number of factors this situation changed rapidly in Canada during the mid-sixties. The development of early ambulation after surgery and the increased use of day-surgical procedures greatly decreased the average length of stay in hospitals. This factor, together with the discovery of new advanced surgical procedures led to a relative decline in active care beds and a great rise in the number of tertiary care or special care beds in hospitals.

Most recently, the development of new medical procedures such as ultrasound and nuclear medicine have led to major increases in the diagnostic areas of hospitals. These policy and technological changes together with the decision to fully air condition hospitals, led to major changes in how hospitals were conceived and designed. The constraints of natural ventilation were no longer applicable and hospital plans became deeper. As a result greater reliance was placed on artificial illumination and the need for good lighting design became more apparent.

These factors together with the recent development of new building materials, light sources and luminaire designs now permit hospital designers to conceive of hospitals as a conglomeration of distinctive areas with each area accommodating unique functions requiring specific design solutions. The universal application of the "institutional" style is no longer practicable or desirable.

Hospitals today contain functions that are similar to those found in other building types and architects and engineers are now designing these areas by using experience learned on different projects. Cafeterias are more like restaurants, administration areas are similar to corporate offices, the design of material management and laboratory areas parallel designs found in high technology manufacturing facilities and patient rooms, hostels and on-call suites are increasingly becoming like student residences or motel rooms.

However, certain areas still remain unique to hospitals. These include treatment and diagnostic areas and tertiary care areas such as Intensive Care Units, Coronary Care Units and Spinal Cord Injury Units. In these areas the designer must provide lighting that will permit the performance of tasks requiring a high degree of visual acuity. In operating rooms, three sources of illumination are now commonly used. These include ceiling mounted fluorescent fixtures with several switching options, incandescent fixtures on dimmers to provide low background lighting for operations using microscopes or fibre optical devices and one or more surgical fixtures with controls to adjust the focal length and intensity of the light.

In advanced tertiary care units up to seven independently controlled lighting sources can be found at each patient's bed. In addition to an uplight and downlight at the patient's head these would also include a night light, a nursing task light, a Luxo lamp, and two overhead fixtures for examination purposes. One of these would be a two by four foot fluorescent fixture with a ½" x ½" parabolic louver surmounted by a lens; the second exam light would be an incandescent fixture with a dimmer control. The second fixture which is mounted at the toe-end of the patient because of heat build up, is used to correct the chromatic distortions of the fluorescent fixture.

Views to the outside are important for both psychological and physiological reasons. Psychologically they provide needed relief from environmentally controlled interior spaces. Equally important, they provide a means of orienting oneself within large buildings. Knowing where one is, is extremely important for lessening the anxiety of both patients and visitors within a hospital.

In order to increase the amount of sunlight in the interior areas of modern air conditioned hospitals, it has been necessary to develop new types of plans. One example, as seen in figure 1, is the tower plan for the new Baycrest Chronic Care Hospital in Toronto. Here an off-set has been provided in the floor plan to decrease the apparent length of the corridors and to permit sunlight to enter the central core area. Another example is the clover-leaf floor plan, as seen in figures 2, 3, and 4, of the new Scarborough Grace General Hospital. In this case the public elevators on all levels open to a generous view to the exterior. In addition, the courtyards formed between the nursing units provide exterior therapeutic areas and permit sunlight to reach the central area of the plan immediately behind the elevator core.

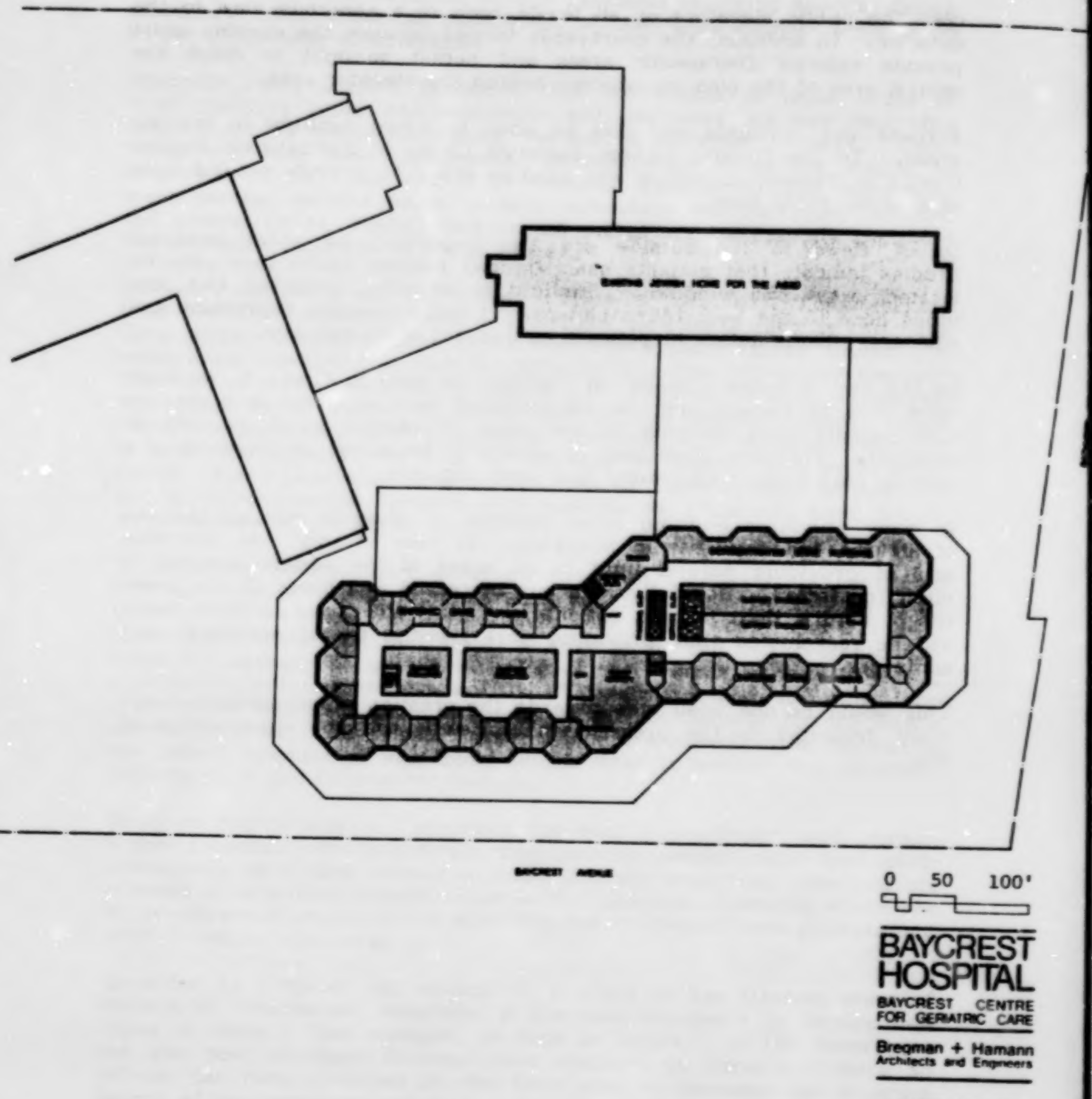
Atriums and skylights can also be used to bring sunlight to interior areas. In the Ontairo Cancer Society's Clinic at Sunnybrook Medical Centre in Toronto an atrium was used in order to provide natural light to a below grade floor.

Direct views to the outside are also important for other reasons. Studies indicate that patients near windows recover faster than patients located away from windows. Sunlight is warming, uplifting and provides hope to the bed-ridden patient. It helps alleviate depression and minimizes disorientation in patients coming out of anaesthesia.

In the new Baycrest Hospital in Toronto, as seen in figure 5, we have been able to reconfigure the conventional two-bed room in a manner that permits both patients in the room to receive equal amounts of sunlight. This new room plan is especially beneficial as Baycrest is a chronic care facility with many long-term patients.

In many provinces building codes prohibit or severely restrict the use of atriums and skylights in hospitals. In view of this, the desirable goal of providing natural light to all areas of the modern hospital is often frustrated. Hopefully with our increased awareness of the benefits of natural light to both patients and staff alike, our building codes will be reevaluated thus providing more freedom to our architects and engineers.

This would be one small step towards the creation of hospitals that are truly dedicated to the preservaton of health and the enhancement of life.


EXISTING JEWISH HOME FOR THE AGED
BAYCREST AVENUE
0 50 100'

BAYCREST HOSPITAL

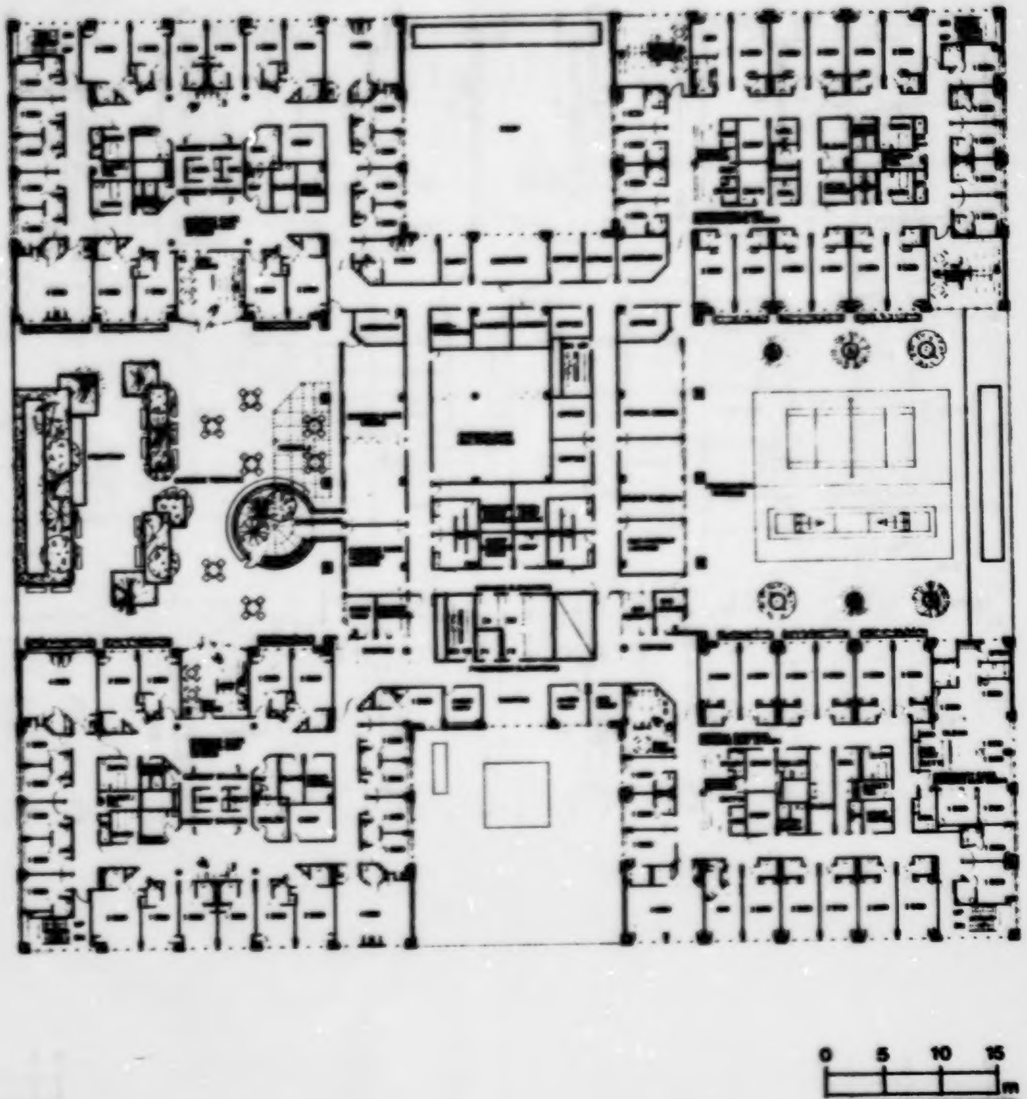
BAYCREST CENTRE FOR GERIATRIC CARE

Bregman + Hamann
Architects and Engineers

FIFTH FLOOR

7918 NOV. 1981

Fig. 1.



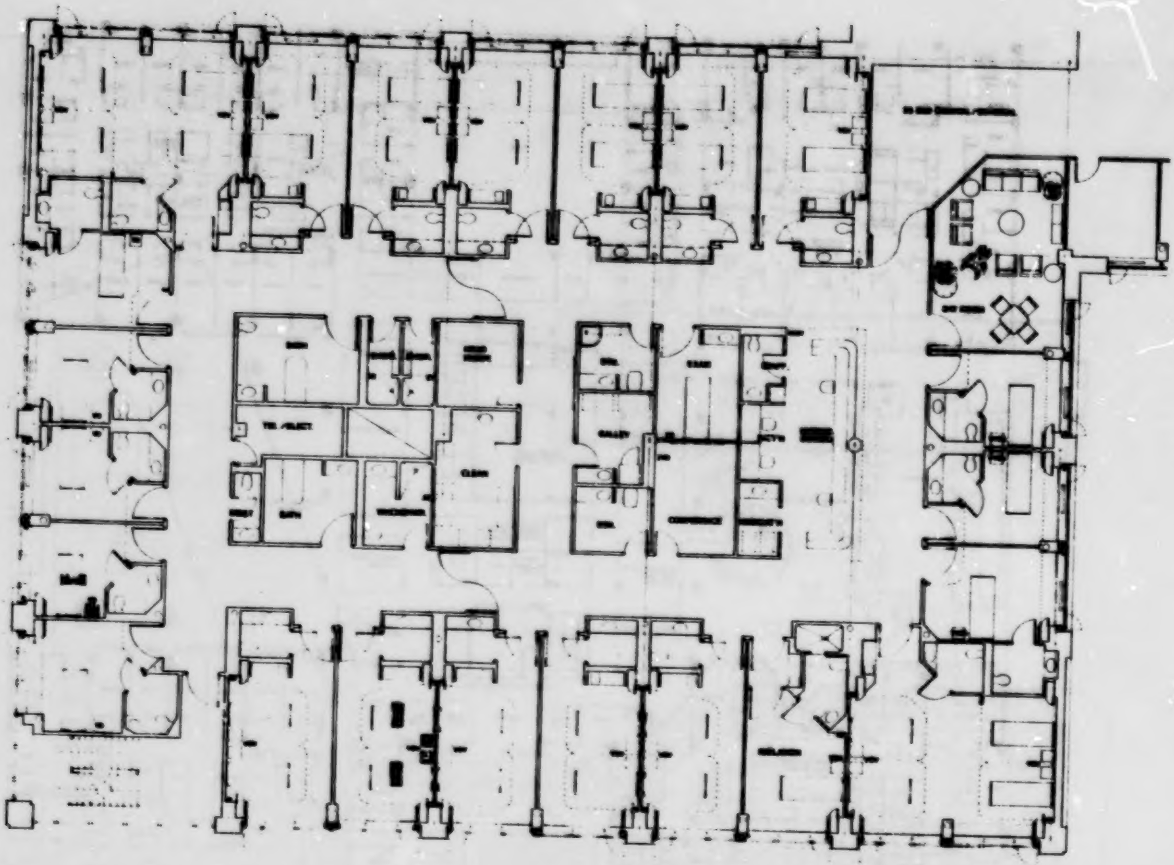
THE SALVATION ARMY
SCARBOROUGH
GRACE
GENERAL HOSPITAL

Bregman + Hamann
Architects and Engineers

LEVEL 3

Fig. 2.

8040 D-05



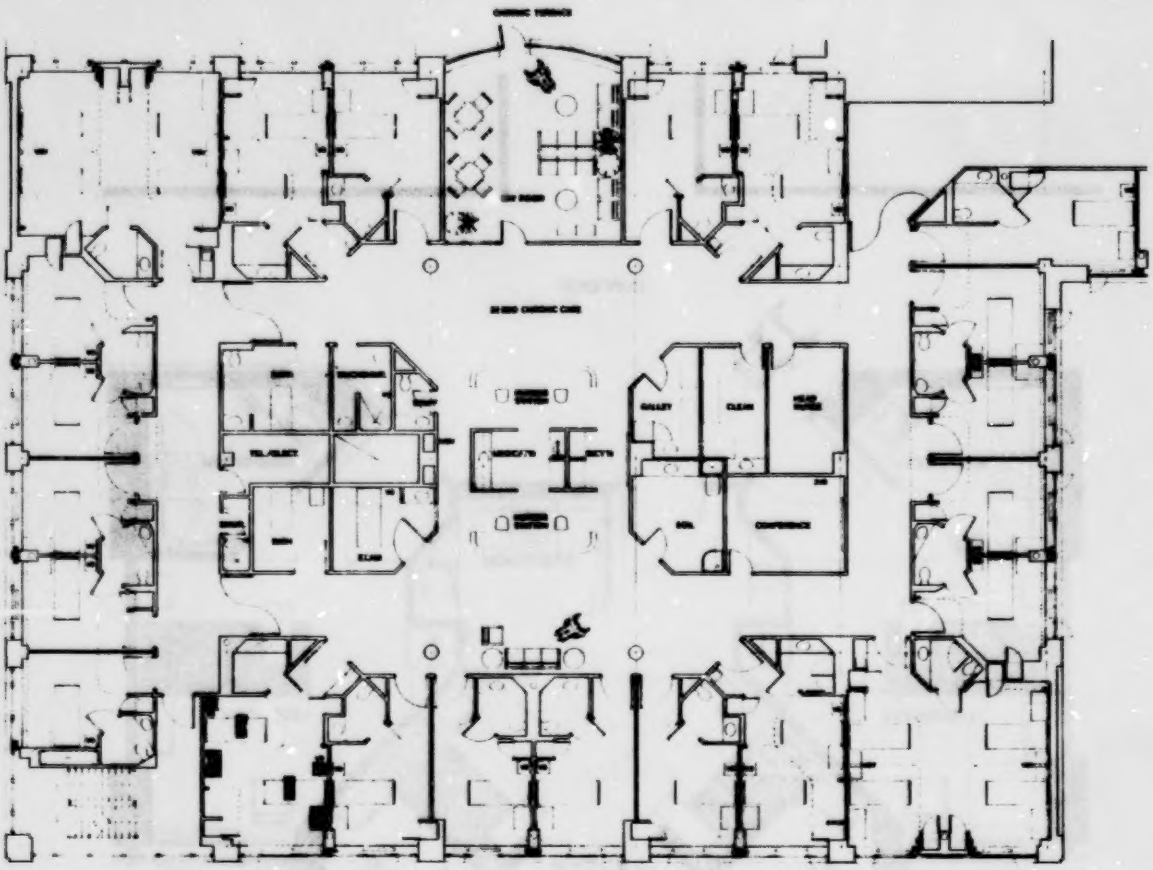
THE SALVATION ARMY
SCARBOROUGH
GRACE
GENERAL HOSPITAL

Bregman + Hamann
Architects and Engineers

TYPICAL
MED./SURG.
NURSING UNIT

8040 D-12

Fig. 3.



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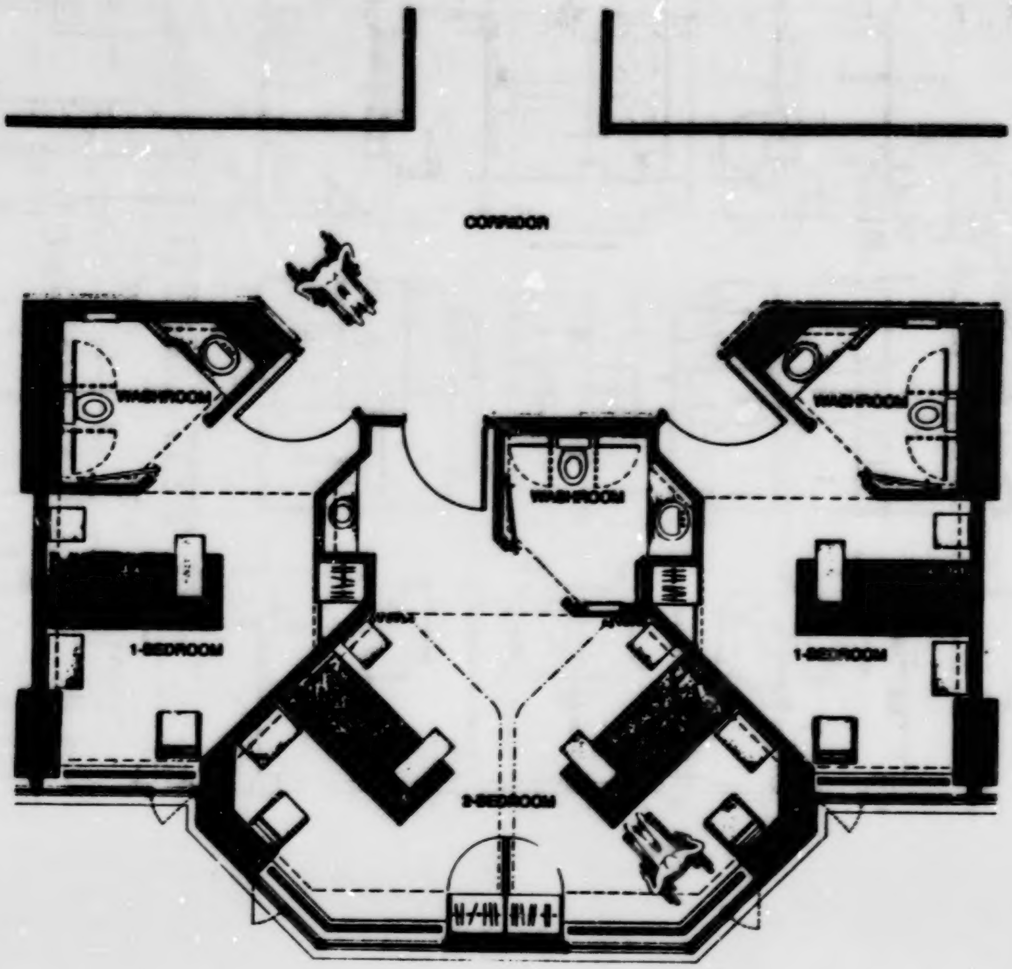
THE SALVATION ARMY
SCARBOROUGH
GRACE
GENERAL HOSPITAL

Bregman + Hamann
Architects and Engineers

TYPICAL
CHRONIC CARE
NURSING UNIT

8040 D-13

Fig. 4.


CORRIDOR
WASHROOM
WASHROOM
WASHROOM
1-BEDROOM
1-BEDROOM
2-BEDROOM

BAYCREST HOSPITAL
BAYCREST CENTRE FOR GERIATRIC CARE

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Fig. 5.

POOR

QUALITY

ORIGINAL